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WAR DEPARTMENT TECHNICAL MANUAL

U.S. Dept. of Army

RADIO

FUNDAMENTALS



WAR DEPARTMENT • 22 MAY 1944

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TM 11-455

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RADIO FUNDAMENTALS



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TM 11-455, Radio Fundamentals, is published for the information and guidance of all concerned.

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- I C 2: T/O 2-10-1, Hq & Hq Tr, Cav Brig (Horse); 2-79, Support Tr, Cav Regt Mecz; T/O & E 2-22, Hq & Hq Tr, Cav Gp, Mecz; 2-27, Cav Rcn Tr (Mecz).
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- I C 4: T/O 4-104, CA Btry, Mine Planter (Cable Ship).
- I C 5: T/O & E 5-16, Hq & Hq Serv Co, Engr C Bn; 5-87, Engr L Pon Co; 5-192, Hq & Hq Co, Engr C Gp; T/O 5-227, Pcht Co, A B Engr Bn; T/O & E 5-218, Co, Armd Engr Bn (Bridge); 5-500, Engr Serv Orgn.
- I C 6: T/O & E 6-10-1, Hq & Hq Btry, Div Arty, Inf or Mtz Div & Hq & Hq Btry. FA Brig; 6-12, Hq & Hq Btry, Mtz FA Gp; 6-26, Hq & Hq Btry, Mtz, FA Bn (Trk-Dr or Tr-Dr); 6-29, Sv Btry, Mtz FA Bn, 105 mm How, Trk-D; 6-36, Hq & Hq Btry, Mtz FA Bn, 155 mm How or 4.5 Gun Trk-Dr or Tr-Dr; 6-39, Sv Btry, Mtz FA Bn, 155 mm How, or 4.5 Gun Trk-Dr.
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- I C 17: T/O & E 17-22, Hq & Hq Co, Armd Gp; 17-98S, Sep Tk Co, Hv.
- I C 18: T/O & E 18-10-1, Hq & Hq Co, TD Gp; T/O 18-27, TD Co.
- I C 19: T/O & E 19-36, Hq & Hq Det, MP Bn, A.
- I C 44: T/O & E 44-10-1, Hq & Hq Btry, AAA Brig; 44-12, Hq & Hq Btry, AAA Gp; 44-117, AAA Gun Btry, SM; 44-127, AAA Auto Wprs Bn, SM; 44-136, Hq & Hq Btry, AAA SL Bn; 44-327, AA Bln try Btry, VLA.

For explanation of symbols see FM 21-6.

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III

This manual supersedes TM 11-455, 17 July 1941.

SECTION I

INTRODUCTION TO RADIO

1. General

a. The success or failure of any military mission depends on the efficiency of its communication system. In these days of high-speed warfare, rapid positive communication is more vitally important than ever before. The advent of mechanized warfare, made possible by the development of motor vehicles, airplanes and tanks, has created a demand for a fast, flexible, and mobile communication system, and radio is the only means of communication which will meet these requirements. The successful coordination of all the units which constitute a modern fighting force would be virtually impossible without radio communication. Hundreds of thousands of radio sets are used by the Army to direct our tanks in battle, detect the approach of hostile airplanes, bring our fighter airplanes into contact with the enemy, and direct our bombers to their targets and bring them safely home. Small portable sets provide instant communication for troops on foot, and powerful fixed stations transmit orders to commanders in the field. All of these sets must be properly operated and maintained; otherwise they will be worthless. The failure of but one radio set in the field may cause the failure of a mission and the loss of many lives.

b. Radio is not difficult to learn if the fundamentals are mastered step by step. A thorough knowledge of these important fundamentals enables a radio operator or technician to understand the equipment he handles and to obtain the best results from its use. Abbreviations common to radio communication work are used throughout this manual to accustom the reader to those terms which are used frequently in all radio publications. A list of these abbreviations and their meanings is given in appendix I.

2. Electrical Background

a. The basic laws which govern the electrical phenomena in radio communication systems are much the same as in ordinary power systems. A discussion of these basic principles of electricity is presented in TM 1-455, including a study of the current and voltage relationships in elementary direct-current (d-c) and alternating-current (a-c) cir-

uits, with applications to power equipment and to measuring instruments. It is assumed that the student is thoroughly acquainted with the material contained in TM 1-455. Basic electrical principles are mentioned in this manual only to the extent necessary to show their application to the fundamentals of radio.

b. An elementary principle of radio transmission can be more easily understood if it is compared to the action of a transformer. (See TM 1-455.) If two coils are coupled together magnetically, and an alternating current is applied to one of the coils (known as the primary), a similar alternating current appears in the second coil (known as the secondary), even though there is no direct physical or mechanical connection between the two coils. In radio transmission a high-frequency (h-f) alternating current, which is known as *radio-frequency* (r-f) current, is applied to a wire known as the *transmitting antenna*. The r-f current flowing through this wire sets up a h-f magnetic field around the wire. If a second wire, known as the *receiving antenna*, is placed somewhere in the magnetic field of the transmitting antenna, r-f current will flow in this second wire. Thus the transmitting antenna corresponds to the primary of a transformer, and the receiving antenna corresponds to its secondary. The effect of the transmitting antenna on the receiving antenna is similar to the effect of the primary on the secondary of a transformer.

3. Frequencies of Communication

a. An a-c wave makes a number of complete cycles every second. The number of cycles per second (cps) determines the frequency of the wave. The frequencies which can be used for communication purposes may be divided into two broad groups: *audio frequencies* and *radio frequencies*.

b. Audio frequencies are those frequencies between about 15 and 20,000 cycles per second to which the human ear normally responds. Sounds which occur at frequencies below 20 cycles per second (such as the staccato tappings of a woodpecker) are recognizable more as individual impulses than as tones. The frequencies that are most important in rendering human speech intelligible fall approximately between 200 and 2,500 cycles per second. The fundamental range of a pipe organ is from about 16 to 5,000 cycles per second, and the highest fundamental note of the flute is about 4,000 cycles per second. Speech and music actually consist of very complicated combinations of frequencies of irregular and changing shape. These are harmonics, or overtones, which are multiples of the fundamental tone, or frequency, and give individual characteristics to sounds of the same fundamental frequency coming from different sources. Thus, a violin and a piano both emitting a 1,000-cycle tone would not sound alike, because of the presence of characteristic overtones. It has been determined by experiment that

the human ear responds best to sounds of about 2,000 cycles per second. Sound waves around 15,000 cycles per second and higher, such as those set up by very high-pitched whistles, are likely to be inaudible to the average ear. Audio frequencies are used to operate telephone receivers, loudspeakers, and other mechanical devices to produce sound waves which are audible to the ear. Although the audio frequencies cannot be used directly for transmission purposes, they play a large part in radio communication.

c. Radio frequencies extend from about 20 kilocycles (20,000 cycles) to over 30,000 megacycles (30,000,000,000 cycles). Since different groups of frequencies within this wide range produce different effects in transmission, radio frequencies are divided into groups, or bands, of frequencies for convenience of study and reference. The bands used for military purposes are shown in table I.

Table I

Band	Frequency range
Low-frequency (l-f)	30 to 300 kc.
Medium-frequency (m-f)	300 to 3,000 kc.
High-frequency (h-f)	3,000 to 30 mc.
Very-high-frequency (v-h-f)	30 to 300 mc.
Ultra-high-frequency (u-h-f)	300 to 3,000 mc.

Since these frequency bands have certain transmission characteristics, it is convenient to note the approximate results which may be expected from the use of various frequencies under normal operating conditions. These results are shown in table II.

Table II

Band	Range		Power required	Antenna length requirements
	Day	Night		
L-f	Long	Long	Very high .	Long
M-f	Medium ..	Long	High to medium..	Long
H-f (3 to 10 mc.)	Short	Medium to long.	Medium ..	Medium
H-f (10 to 30 mc.) ...	Long	Short	Low	Short
V-h-f	Short	Short	Low	Very short

Long range: over 1,500 miles. Medium range: 200 to 1,500 miles. Short range: under 200 miles.

4. Relationship Between Radio Frequency and Wavelength

a. When r-f current flows through a transmitting antenna, radio waves are radiated from it in all directions in much the same way that waves travel on the surface of a pond into which a rock has been thrown. It has been found that these radio waves travel at a speed, or velocity, of 186,000 miles per second (equal to 300,000,000 meters per second). Radio waves are produced by sending a h-f alternating current through a wire. The frequency of the wave radiated by the wire will therefore be equal to the frequency, or number of cycles per second, of the h-f alternating current.

b. Since the velocity of a radio wave is constant regardless of its frequency, to find the wavelength (which is the distance traveled by the radio wave in the time required by one cycle) it is only necessary to divide the velocity by the frequency of the wave. This is an important relationship of radio communication.

$$\frac{300,000,000 \text{ (velocity in meters per second)}}{\text{Frequency (in cycles per second)}} = \text{Wavelength (in meters).}$$

Example: To find the wavelength of a radio wave with a frequency of 100,000 cycles per second:

$$\frac{300,000,000}{100,000} = 3,000 \text{ meters.}$$

This same relationship can be expressed in another way. If the wavelength is known, the frequency can be found by dividing the velocity by the wavelength.

$$\frac{300,000,000 \text{ (velocity in meters per second)}}{\text{Wavelength (in meters)}} = \text{Frequency (in cycles per second).}$$

Example: To find the frequency of a radio wave with a wavelength of 150 meters:

$$\frac{300,000,000}{150} = 2,000,000 \text{ cycles per second (or 2,000 kc).}$$

c. Radio waves are usually referred to in terms of their frequency. Since the frequencies employed in radio transmission extend from several thousand to many hundreds of millions of cycles per second, it is more convenient to refer to them in terms of *kilocycles* per second (kc) and *megacycles* per second (mc).

$$1 \text{ kc} = 1,000 \text{ cycles per second.}$$

$$1 \text{ mc} = 1,000 \text{ kc} = 1,000,000 \text{ cycles per second.}$$

5. Elements of Radio Communication

a. In order to transmit messages from one location to another by radio, the following basic equipment is required. (See fig. 1.)

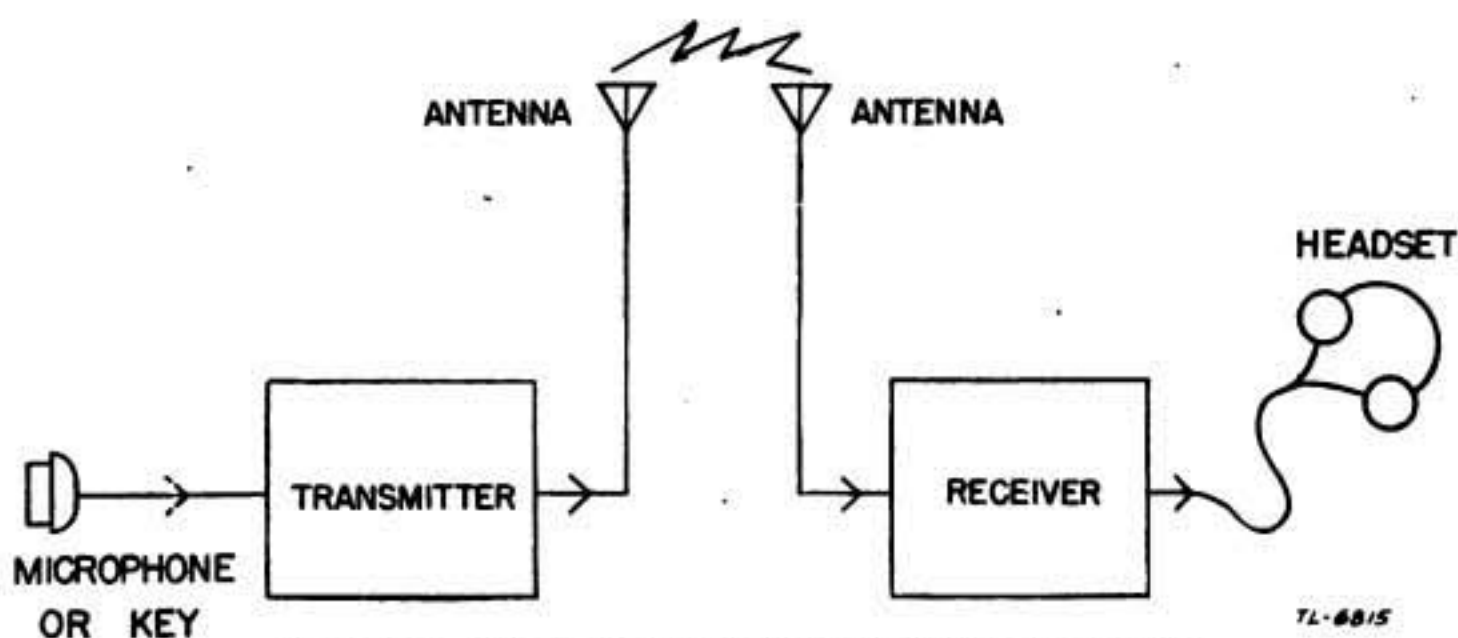


Figure 1. Block diagram of basic radio equipment.

- (1) A transmitter, to generate r-f energy waves.
- (2) A key, or microphone, to control these energy waves.
- (3) A transmitting antenna, to radiate r-f waves.
- (4) A receiving antenna, to intercept some of the radiated r-f waves.
- (5) A receiver, to change the intercepted r-f waves into a-f waves.
- (6) A loudspeaker, or headphones, to change the a-f waves into sound.

b. The simplest possible radio transmitter (fig. 2) consists of a power supply and a device known as an *oscillator*, for generating r-f alternating current. The power supply may consist of batteries, a

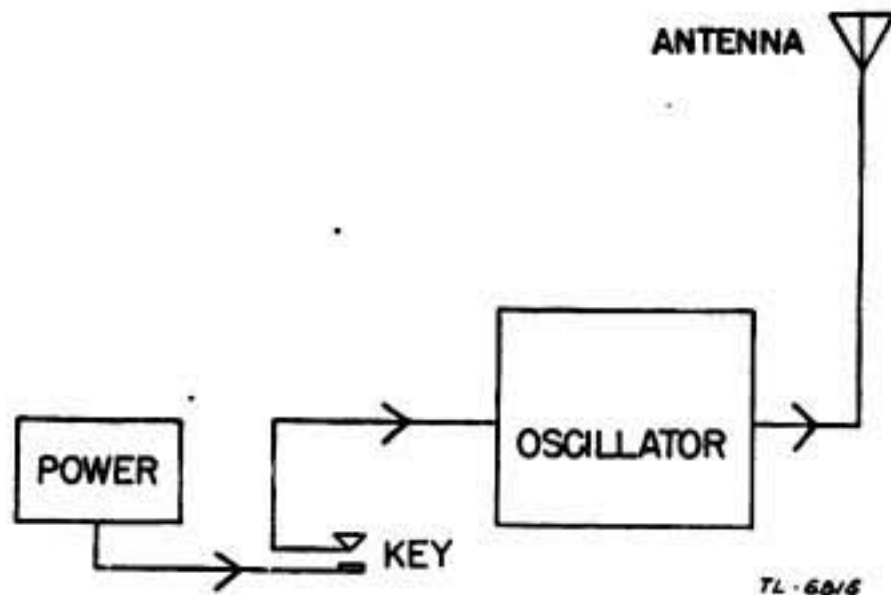


Figure 2. Block diagram of simple radio transmitter.

generator, or an a-c-operated power source. In order to tune such a transmitter to the desired operating frequency, the oscillator must contain a tuned circuit. It is also necessary to have some method of controlling the r-f energy generated by this transmitter, if messages are to be sent by this means. The easiest way of doing this is to use a telegraph key (which is merely a type of switch for controlling the flow of electric current) connected in series with the power supply and the oscillator. When the key is operated, the power applied to the oscillator to establish a flow of current is turned on and off for varying lengths of time, to form dots or dashes of r-f energy. Since the output

power, or r-f energy, generated by this oscillator is normally not great enough to permit transmission over long ranges, it is seldom used alone as a radio transmitter. In order to increase, or amplify, the output of

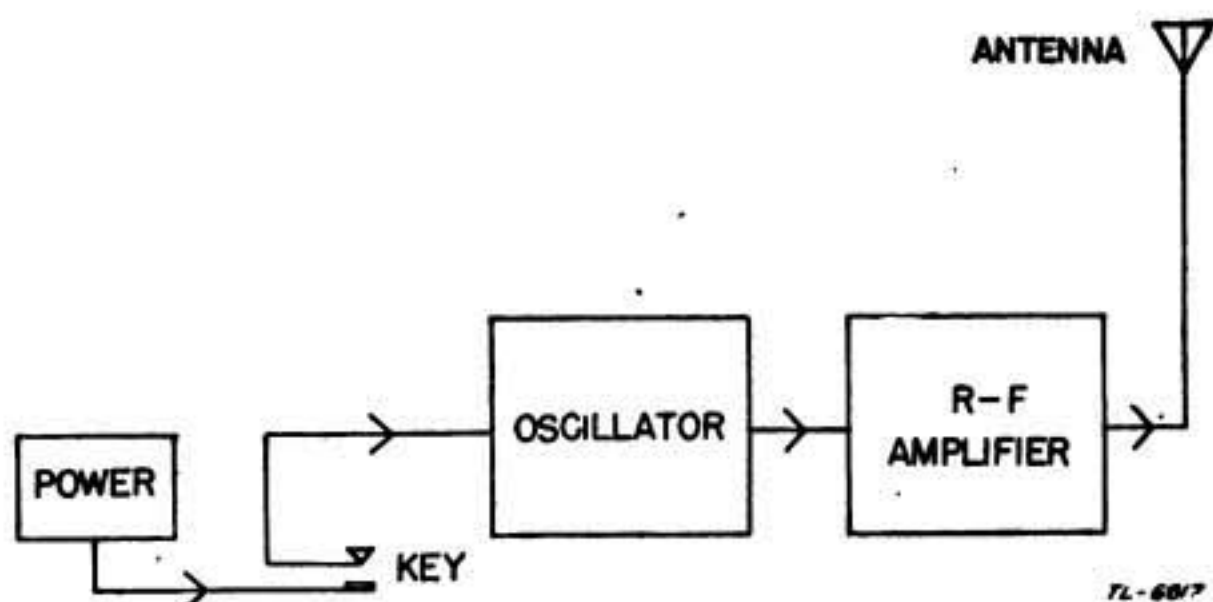


Figure 3. Block diagram of oscillator-amplifier transmitter.

the oscillator, a device known as a *r-f amplifier* is generally used in modern radio transmitters. The addition of this stage is shown in figure 3. Such a transmitter is entirely satisfactory for practical purposes where only radiotelegraph or code transmission is desired. In order to transmit messages by voice, however, it is necessary to find some way of controlling the output of the transmitter in accordance with the voice frequencies (audio frequencies). In modern radiotelephone transmitters this is done by means of a modulator, which increases or decreases the output of the transmitter in accordance with

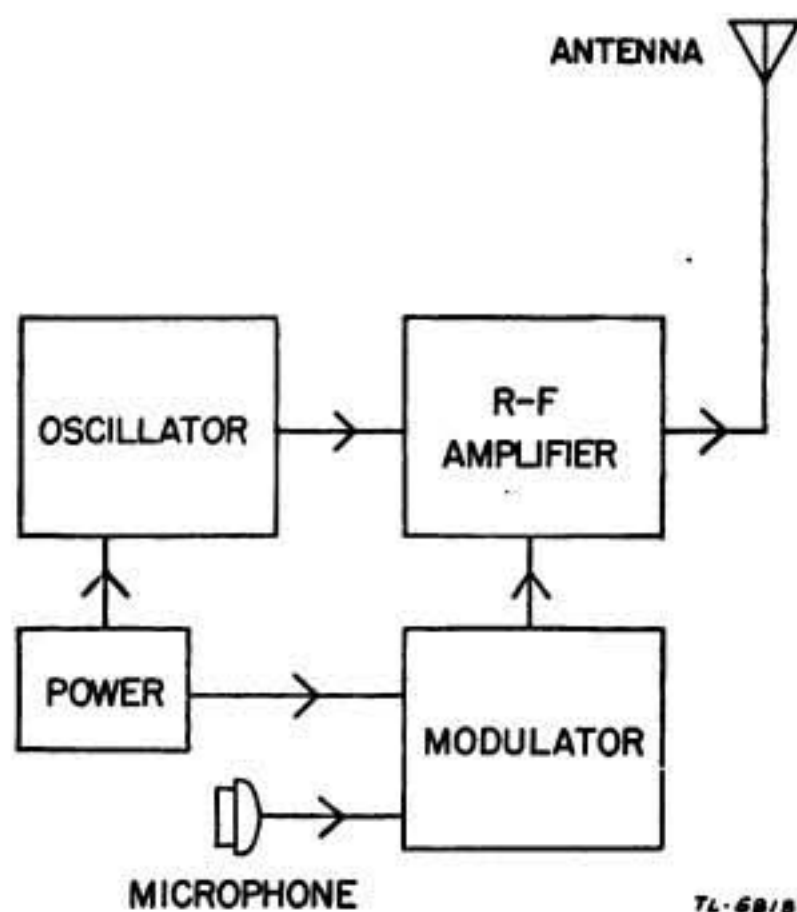


Figure 4. Block diagram of radiotelephone transmitter.

the voice frequencies generated when speech enters a microphone. This process is known as *modulation*, and a r-f wave affected in this manner

is known as a *modulated wave*. Figure 4 shows the addition of the modulator and microphone required to change the radiotelegraph transmitter into a radiotelephone transmitter.

c. The radio receiver operates in a manner different from that of the transmitter just discussed. Consider the diagram of a simple radio receiver. (See fig. 5.) Radio-frequency waves (from a transmitter) are reaching the antenna of the receiver. If a pair of headphones (headset) is connected directly to the receiving antenna in an attempt to receive the incoming radio waves, the attempt would not be successful, because the human ear will not respond to radio frequencies. A method is therefore needed whereby intelligence in the form of audio-frequency waves can be extracted from radio-frequency waves, and converted into sound by a headset. The circuit which is used in radio receivers to

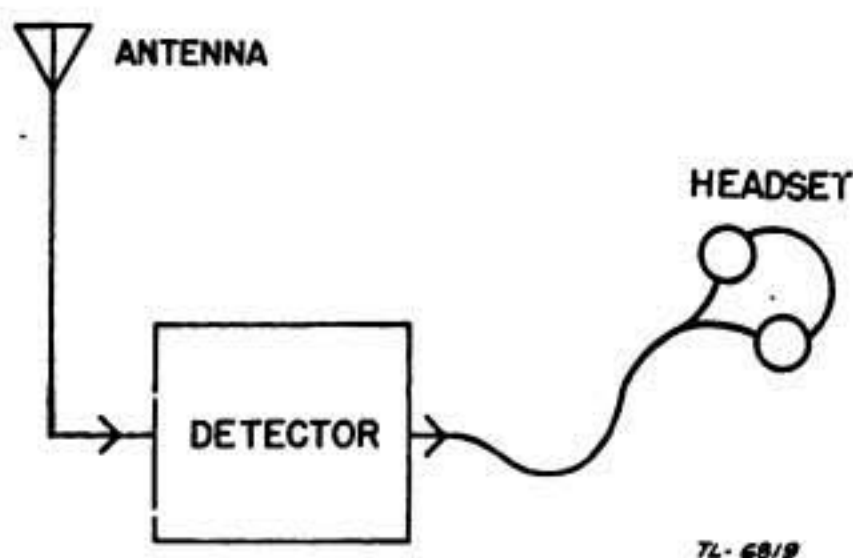


Figure 5. Block diagram of simple radio receiver.

accomplish this is known as a *detector*, since it actually detects the incoming signal (radio wave). Since it is known that the radio transmitter is sending out radio waves of a certain frequency, the receiver must have some means of tuning in, or selecting the frequency of the desired radio wave. This is necessary to avoid receiving many radio signals of different frequencies at the same time. That part of a detector which is used to tune in the desired signal is called a *tuned circuit*. Because a radio signal diminishes in strength, or amplitude, at a very rapid rate after it leaves the transmitting antenna, it is

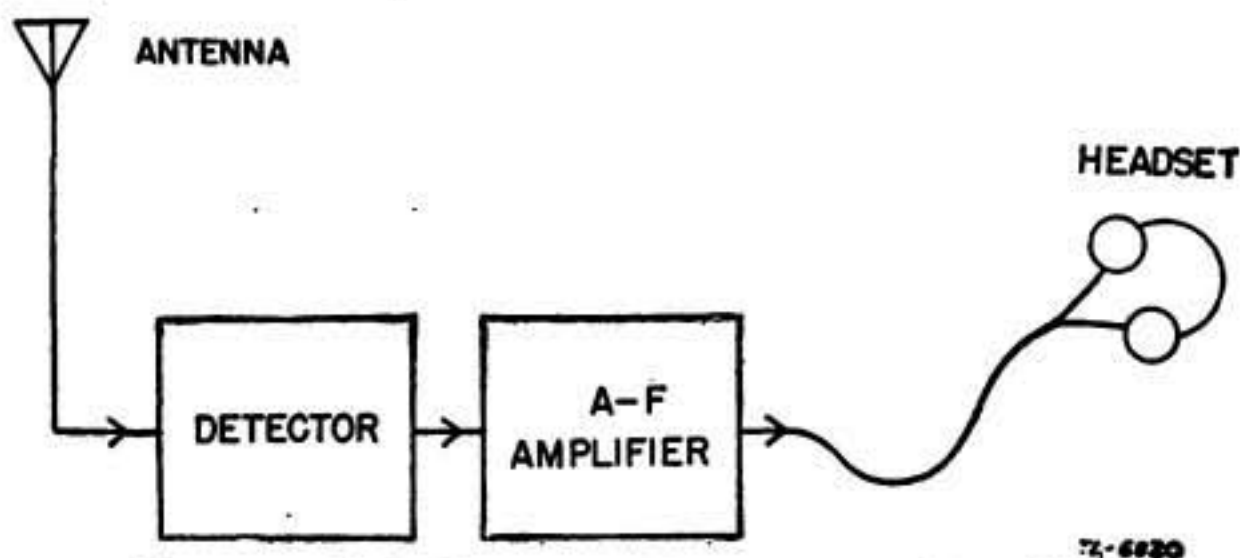


Figure 6. Block diagram of detector and a-f amplifier.

seldom possible to use a detector alone to tune in the desired signal. The greater the distance between the transmitting and receiving antennas, the greater will be the reduction, or loss, in signal strength. By the time it reaches the receiver, the signal may be so weak that the sound in the headset is too faint to be understood. The actual r-f signal voltage picked up by a receiving antenna in normal communication work is usually only a few microvolts, or millionths of a volt. In order to increase the level of the a-f output of the detector to obtain satisfactory headset operation, an a-f amplifier is used in most radio sets. Figure 6 shows an a-f amplifier added to the simple radio receiver. If it is desired to increase the sensitivity (ability to receive weak signals) of the receiver still more, it will be necessary to amplify the r-f signal before it reaches the detector. This is done by the use of an r-f amplifier. Since the r-f amplifier, like the detector, is provided with

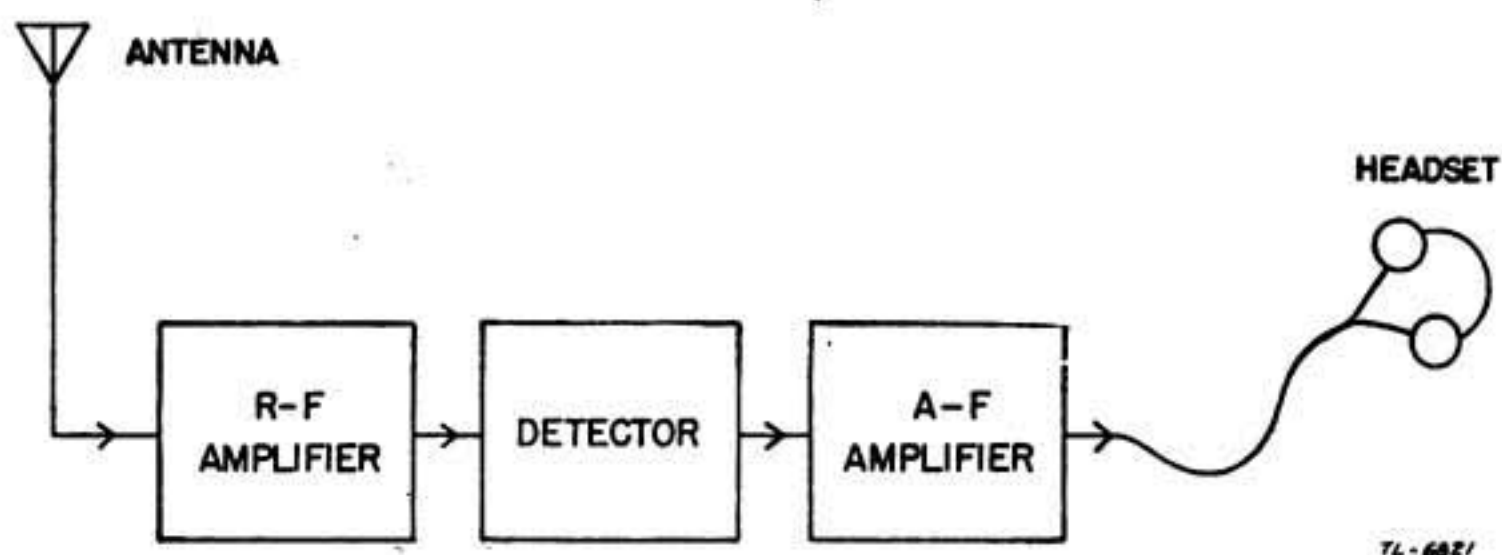


Figure 7. Block diagram of complete radio receiver.

one or more tuned circuits, so that it amplifies *only* the desired signal, the addition of an r-f amplifier to the receiver gives not only greater sensitivity, but also greater selectivity (ability to separate signals). The essentials of a modern radio receiver are shown in figure 7.

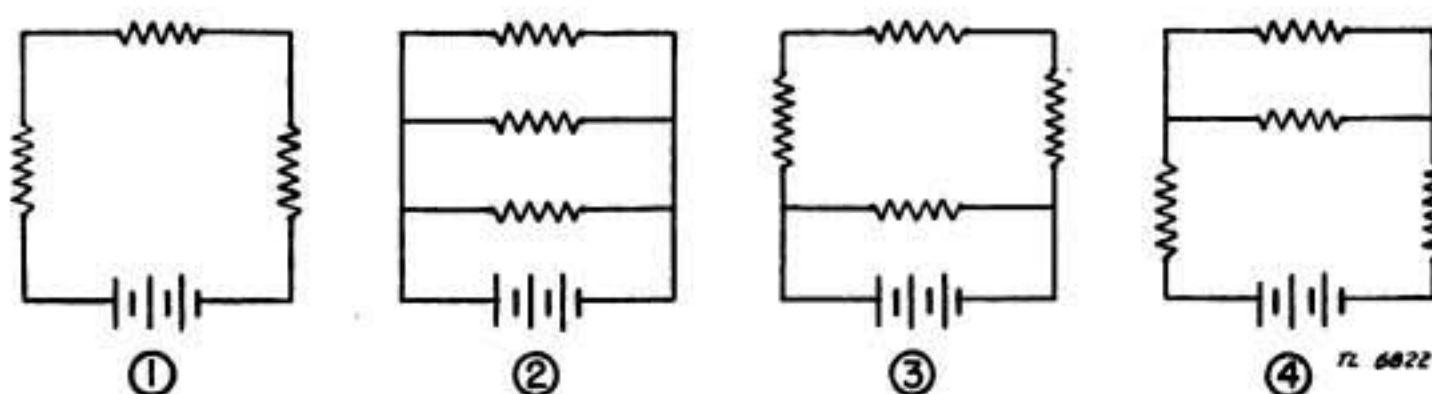
SECTION II

CIRCUIT ELEMENTS AND SYMBOLS

6. Simple Circuits

a. It has been shown that radio transmitters and receivers are made up of a number of circuits, each of which has a definite job to do in the operation of the whole. The failure of one part in any of these various circuits can cause the failure of the entire radio set. It is therefore necessary to study carefully such circuits and their individual parts.

b. There are three general types of electrical circuits, known as *series* circuits, *parallel* circuits, and *series-parallel* circuits, depending on the arrangement of parts. (See fig. 8.) The principle of operation of these



- ① *Series-connected circuit.*
② *Parallel-connected circuit.*
③, ④ *Series-parallel, combination circuits.*

Figure 8. Simple circuits.

simple circuits is discussed in TM 1-455. A simple relationship, known as Ohm's law, exists between the voltage, current, and resistance in electrical circuits. The student should become thoroughly familiar with all three forms of Ohm's law, since it is very useful in determining the voltage, current, or resistance in an electrical circuit. When any two of these values are known, the third can easily be found.

c. Ohm's law simply states that *the current flowing in a circuit is equal to the voltage applied to the circuit divided by the resistance.*

$$I \text{ (amperes)} = \frac{E \text{ (volts)}}{R \text{ (ohms)}}$$

This is the form that is used when the voltage applied to the circuit and the resistance of the circuit are both known, and the value of the current flowing in the circuit is wanted.

Example: If 500 volts are applied to a circuit which has a resistance of 5,000 ohms, the current in the circuit will be—

$$I = \frac{500}{5,000} = \frac{1}{10} = 0.1 \text{ ampere.}$$

d. If the current and the resistance of the circuit are known, the voltage applied to the circuit can be found by use of the second form of Ohm's law, which states that *the current times the resistance equals the voltage*.

$$E \text{ (volts)} = I \text{ (amperes)} \times R \text{ (ohms).}$$

Example: If a current of 3 amperes is flowing through a circuit having 70 ohms resistance, the voltage applied to the circuit will be—

$$E = 3 \times 70 = 210 \text{ volts.}$$

e. If the values of the current and voltage are known, the resistance of the circuit can be found by the third form of Ohm's law, which states that *the resistance equals the voltage divided by the current*.

$$R \text{ (ohms)} = \frac{E \text{ (volts)}}{I \text{ (amperes)}}$$

Example: If a current of 0.25 ampere flows in a circuit to which 100 volts is applied, the resistance of that circuit will be—

$$R = \frac{100}{0.25} = 400 \text{ ohms.}$$

f. D-c circuits and a-c circuits are dealt with separately in TM 1-455, and no attempt is made to consider circuits in which both direct current and alternating current are present at the same time. Since both direct current and alternating current are present simultaneously in most radio circuits, it is important to understand the manner in which the various parts of a radio circuit control the current flow.

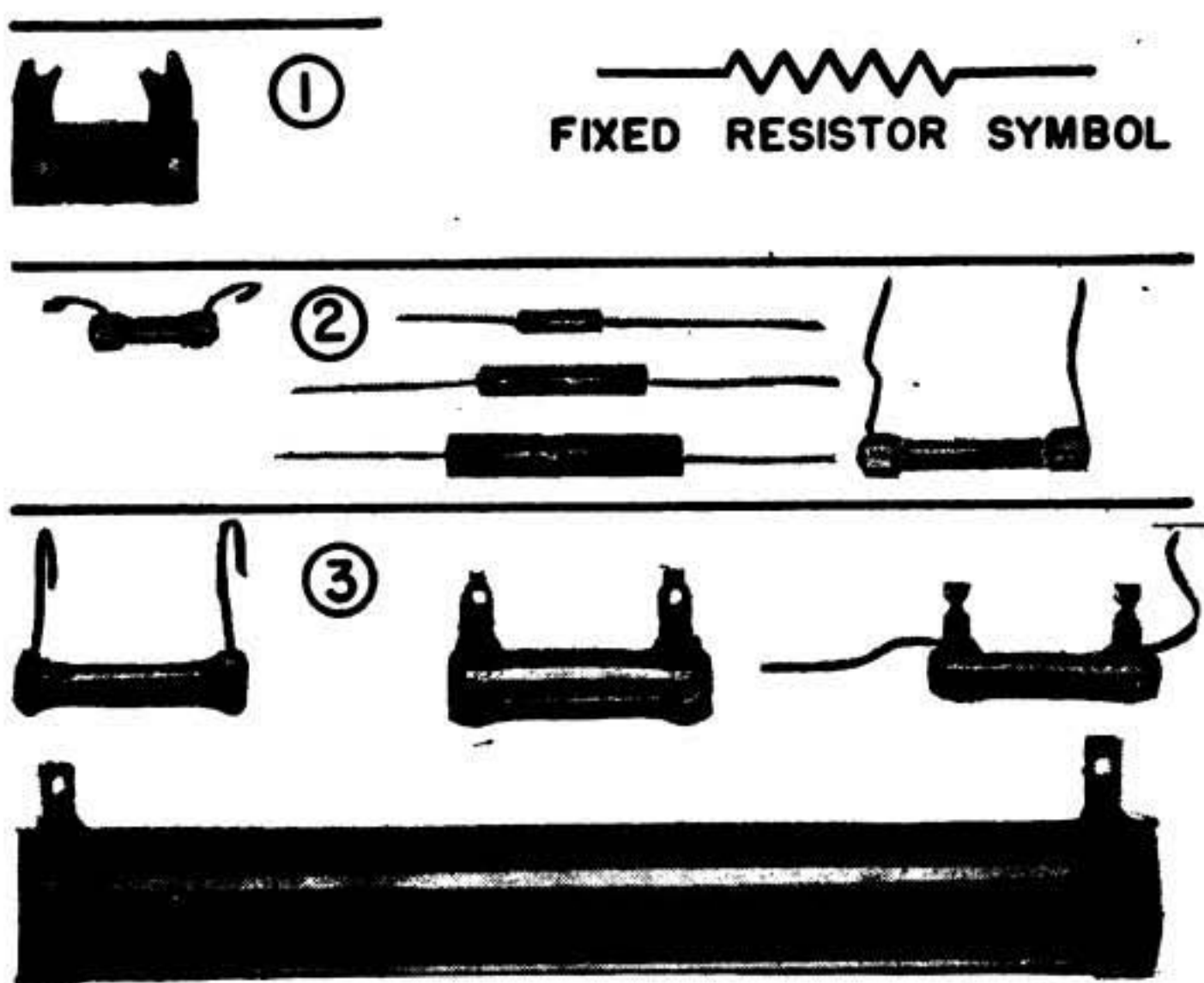
7. Circuit Elements

Any radio circuit is a combination of parts arranged to control the flow of current in such a manner that certain desired results are produced. These parts are called circuit elements. The three main circuit elements used in radio work are *resistors*, *inductors*, and *capacitors*.

8. Resistors

a. A resistor is a circuit element designed to introduce resistance into the circuit, so as to reduce or control the flow of current. Resistors may be divided into three general types, according to their construction. These are known as *fixed resistors*, *adjustable resistors*, and *variable resistors*.

b. Fixed resistors are used to introduce a constant value of resistance into a circuit. Their size and construction are determined by the



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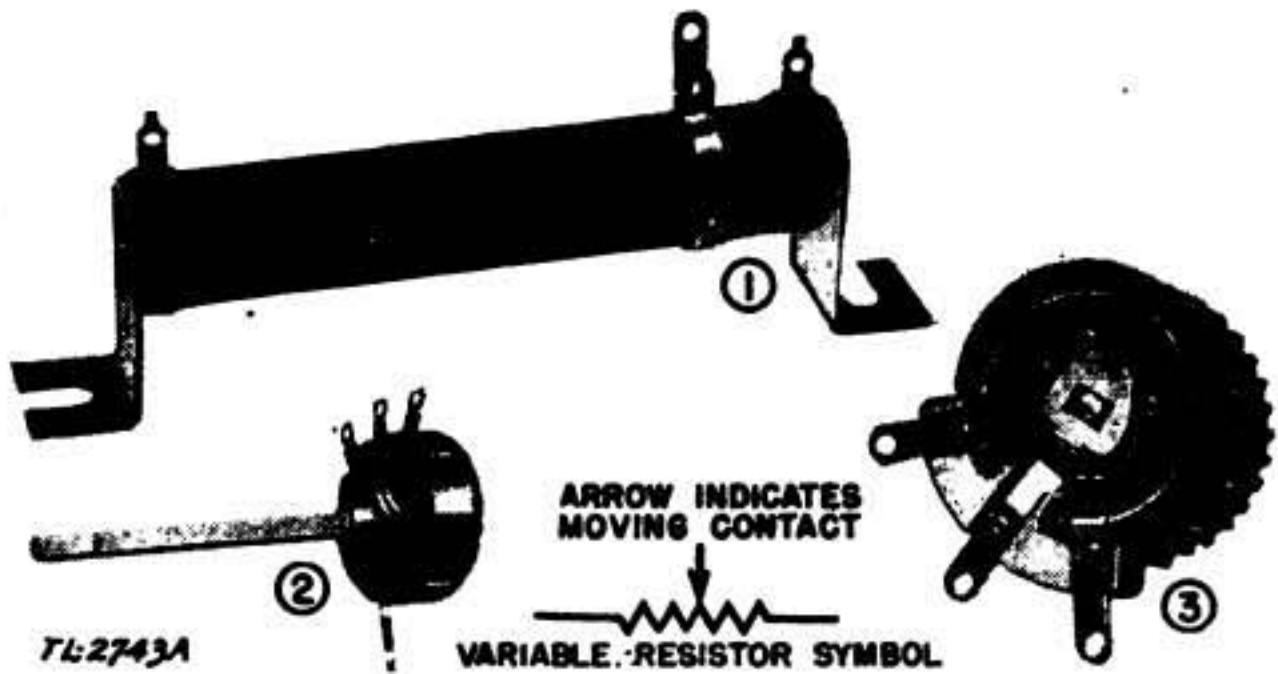
- ① Wire-wound resistor.
- ② Low-wattage carbon resistors.
- ③ High-wattage carbon resistors.

Figure 9. Fixed resistors.

amount of power they must carry. For low-power requirements, small carbon or metallized resistors are used; where heavier power must be carried, larger resistors of wire-wound construction are employed. Several types of fixed resistors are shown in figure 9, together with the symbol which is used to represent them on circuit diagrams. Fixed resistors are often provided with colored markings to indicate their resistance value and accuracy (tolerance). This system of marking, called the Resistor Color Code, is simple, and should be memorized for future reference. Table III shows the complete Resistor Color Code, and gives several examples of its use. When a color-coded fixed resistor does not bear either a gold or silver tolerance marking, it should be remembered that the resistor is only accurate to within 20 percent of its marked value in ohms. Large fixed resistors, for use in highpower circuits, are found without the color coding, but the value in ohms generally is printed somewhere on the resistor.

c. Adjustable resistors are used where it is necessary to change or adjust the value of the resistance in a circuit from time to time. In its

usual form, the adjustable resistor is wire-wound, and has one or more sliding collars which may be moved along the resistance element to select any desired resistance value. It is then clamped in place. Figure 10① shows an adjustable resistor.

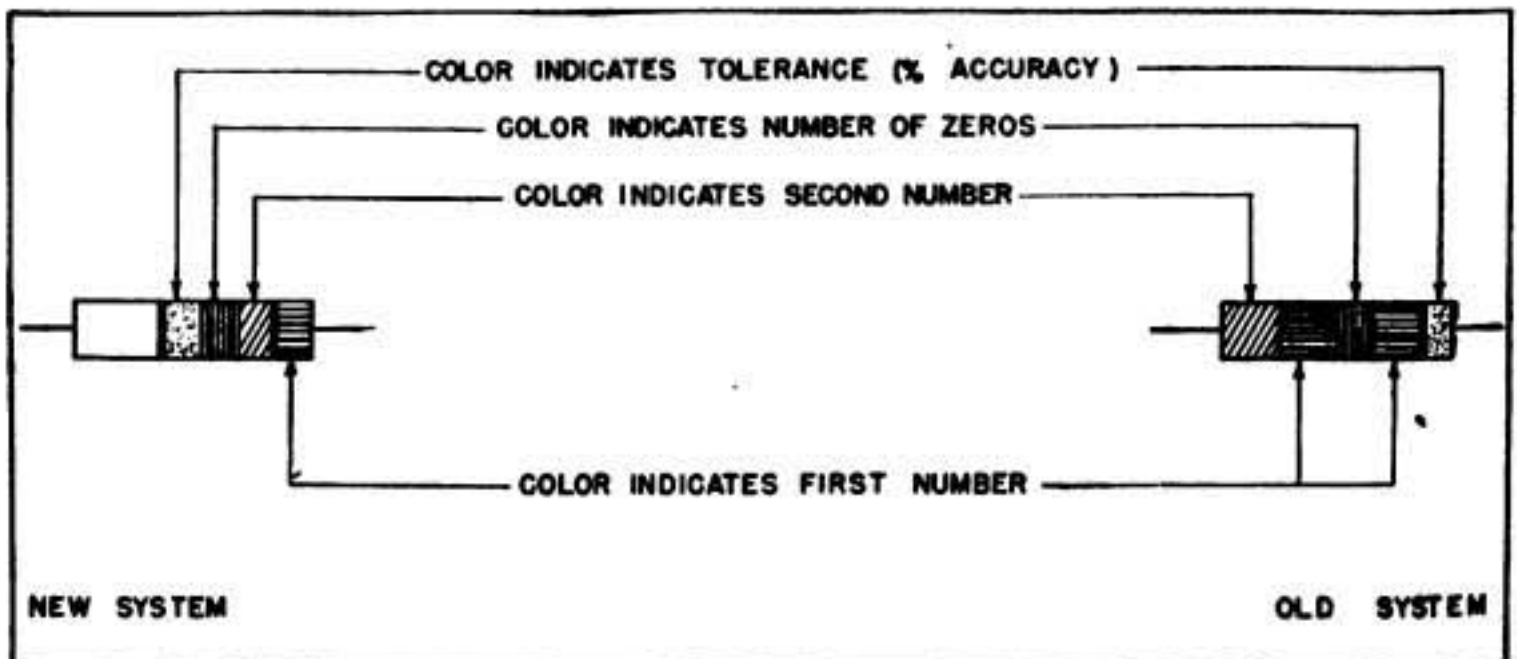


- ① Adjustable power resistor.
- ② Potentiometer for volume control.
- ③ Potentiometer for power supply.

Figure 10. Adjustable and variable resistors.

d. Variable resistors are used in a circuit when a resistance value must be changed frequently. Depending on the power requirements, variable resistors are either of carbon or wire-wound construction. The actual resistance element of the variable resistor is usually circular in shape, and the sliding tap, or "arm," which makes contact with it is provided with a knob and a shaft, by means of which the resistance can be varied smoothly. If both ends of the resistance element are provided with connection terminals (in addition to the sliding arm) the

Table III. Resistor Color Code.



TL-6895

Color	Number
Black	0
Brown	1
Red	2
Orange	3
Yellow	4
Green	5
Blue	6
Violet	7
Gray	8
White	9
Gold	5 percent accuracy
Silver	10 percent accuracy

NOTE. If no gold or silver marking appears (to indicate tolerance) accuracy is 20 percent (standard tolerance).

Example: A 50,000-ohm resistor, of standard tolerance, would be indicated by a green ring (5), a black ring (0), and an orange ring (000), as shown in the new system of marking above. In the old system of marking, shown above on the right hand side of the page, the resistor would be painted green (5), with a black end (0), and an orange dot or ring in the center (000).

variable resistor is called a *potentiometer*. Figure 10② shows a potentiometer used as a volume control for a radio receiver; figure 10③ shows a potentiometer wound of heavier wire for use in a power supply circuit. If only one end of the resistance element and the sliding arm are brought out to connection terminals, the variable resistor is called a *rheostat*. The symbol for adjustable resistors is the same as that for variable resistors.

9. Resistance Calculations

a. In repairing radio sets it is sometimes found that the exact replacement parts are not at hand. It then becomes necessary to use whatever parts are available to make the repair. This is particularly true in the case of resistors, since many different resistors of different values and sizes are required in transmitters and receivers. A repair depot would have to carry thousands of resistors in stock at all times, to have on hand the exact replacements required for the repair of radio equipment in the field. Obviously this is not possible, and the competent radio repairman must know how to calculate the resistance values of combinations of resistors (in series and parallel) so that he can use available resistors to make emergency repairs.

b. The total resistance of several resistors connected in series is equal to the sum of the resistances of the individual resistors.

$$R_t (\text{total}) = r_1 + r_2 + r_3.$$

Example: The total resistance of three resistors connected in series, the values of which are 50,000 ohms, 100,000 ohms, and 250,000 ohms respectively, will equal—

$$R_t = 50,000 + 100,000 + 250,000 = 400,000 \text{ ohms.}$$

c. If several resistors of equal value are connected in parallel, the

total resistance will equal the value of one resistor divided by the number of resistors.

$$R_t \text{ (total)} = \frac{r \text{ (of one resistor)}}{n \text{ (No. of resistors)}}$$

Example: If five 50,000-ohm resistors are connected in parallel, the effective resistance of the combination will equal—

$$R_t = \frac{50,000}{5} = 10,000 \text{ ohms.}$$

If several resistors of unequal values are connected in parallel, the reciprocal of the total resistance (one divided by the total resistance) will be equal to the sum of the reciprocals of the individual resistors.

$$\frac{1}{R_t} = \frac{1}{r_1} + \frac{1}{r_2} + \frac{1}{r_3}$$

Example: The total resistance of three resistors connected in parallel, the resistances of which are 40,000 ohms, 20,000 ohms, and 8,000 ohms, respectively, will equal—

$$\begin{aligned} \frac{1}{R_t} &= \frac{1}{40,000} + \frac{1}{20,000} + \frac{1}{8,000} \\ &= \frac{1}{40,000} + \frac{2}{40,000} + \frac{5}{40,000} \\ \frac{1}{R_t} &= \frac{8}{40,000} = \frac{1}{5,000} \\ R_t &= 5,000 \text{ ohms.} \end{aligned}$$

d. When current flows through a resistance, part of the electrical energy is changed into heat; thus it is said that a resistance consumes power. A resistor in a circuit consumes power according to the voltage applied to it and the current which flows through it. This is a power loss (since heat produced by a resistor in a radio circuit is of no use), and is known as the *dissipation* of the resistor. It is very important to know how much power a given resistor dissipates in a given circuit in order to make any repairs to the circuit. If a replacement resistor cannot safely dissipate the required power, it will overheat and possibly burn out; and the high heat it radiates may damage other parts. For this reason resistors are rated in watts dissipation, so that the maximum power a resistor will dissipate is known. Thus, a 2-watt resistor can safely dissipate up to 2 watts of power, and a 5-watt resistor can safely dissipate up to 5 watts. It is advisable when replacing defective resistors to use resistors capable of dissipating more than the known power of the circuit; a safe rule is to use resistors rated at least 1½ times the required power.

e. To determine the *power dissipation in watts* when the voltage and current are known, *multiply the voltage by the current.*

$$P \text{ (watts)} = E \text{ (volts)} \times I \text{ (amperes)}.$$

Example: If 50 volts applied to a given resistor cause a current of 0.5 ampere to flow through it, the power dissipation of the resistor will be equal to—

$$P = 50 \times 0.5 = 25 \text{ watts.}$$

When the value of the resistance and the current through the resistor are known, *multiply the current squared* (the current times itself) *by the resistance to obtain the power dissipation in watts.*

$$P = I^2 \times R.$$

Example: If a current of 2 amperes flows through a resistance of 10 ohms, the power dissipation in watts will be equal to—

$$P = 2^2 \times 10 = 2 \times 2 \times 10 = 40 \text{ watts.}$$

f. Resistance offered to the flow of current by a resistor is the same for both alternating current and direct current. In the case of alternating current, the resistance remains the same regardless of frequency.

10. Reactance

a. Two other circuit elements, inductors and capacitors, are also used to oppose the flow of current in circuits containing both alternating current and direct current. However, this opposition, unlike the resistor just studied, is not the same for both alternating current and direct current. The inductor or capacitor reacts in a different way to various a-c frequencies; in other words, the opposition to the flow of current does not remain constant as the a-c frequency is varied.

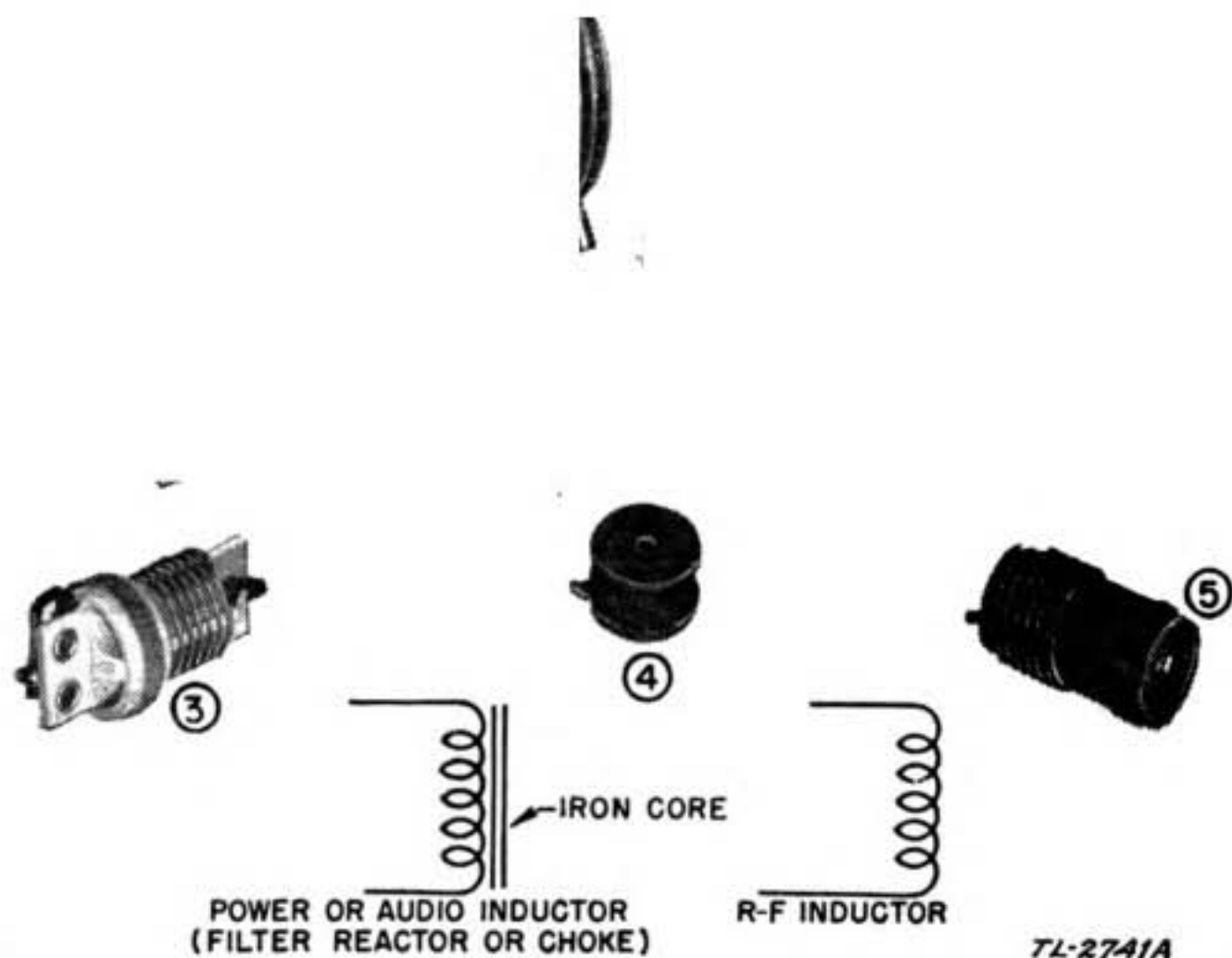
b. In the case of the inductor, the opposition offered to the flow of alternating current will become greater if the frequency is increased. In the case of the capacitor, the effect is just the opposite, and the opposition will decrease as the frequency is increased. This opposition that a capacitor or inductor offers to the flow of alternating current is known as its *reactance*. The reactance of an inductor is called *inductive reactance*; the reactance of a capacitor is called *capacitive reactance*. Both inductive reactance and capacitive reactance are measured in ohms.

11. Inductors

a. An *inductor* is a circuit element designed to introduce a certain amount of inductive reactance into a circuit. An inductor may take any number of physical forms or shapes, but basically it is nothing more nor less than a *coil* of wire. The unit of inductance measurement

is the *henry*, and the terms *millihenry* and *microhenry* are also used. One henry is equal to 1,000 millihenrys, which in turn are equal to 1,000,000 microhenrys. The inductance of an air-core coil increases as the size of the coil or the number of turns of wire is increased. The use of magnetic metal (such as iron) for the core of the coil will increase its inductance; a nonmagnetic metal (such as brass or copper) will decrease the inductance. The inductive reactance of any coil is increased as its inductance is increased. There are three general types of inductors: fixed, adjustable, or variable.

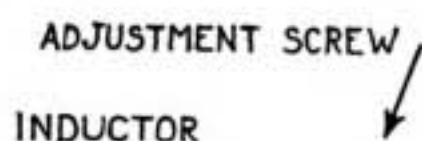
b. Fixed inductors have a constant value of inductance in a circuit. Most of the coils used in radio work are of the fixed type. The coils used in the tuned circuits of radio transmitters and receivers usually have air cores. The number of turns of wire depends on the frequency range to be covered. The only difference between transmitting and receiving inductors is in their size, since transmitting coils must stand considerably more current and voltage than those used in receivers. A typical transmitting coil is shown in figure 11①, and consists of a single winding of heavy wire.



- ① *Single-winding tank inductor for high-power transmitters.*
- ② *Plug-in type r-f transformer for medium-power transmitters.*
- ③ and ⑤ *Small r-f transformers used in h-f receivers and transmitters.*
- ④ *Small r-f inductor or choke coil used in receivers or low-power transmitters.*

Figure 11. Typical r-f inductors and transformers.

c. *Adjustable inductors* found in modern radio equipment are of two main types. The first, and simplest, consists of a coil which is provided with several taps and a switch, or clip, so that the inductance may be adjusted in several steps. This type is found mainly in the antenna circuit of radio transmitters, where it is desirable to adjust the inductance of the coil to suit the varying requirements of different antenna lengths. In the second type, the coil is provided with a magnetic core, which may be moved in or out by means of an adjustable



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Figure 12. *Permeability-tuned inductor.*

setscrew. This type of adjustable inductor, known as a *permeability-tuned inductor*, is sometimes used in transmitters and receivers in tuned circuits intended to operate at only one frequency. Figure 12 shows the use of a permeability-tuned inductor in a tuned-circuit assembly, and gives the symbol by which this type of adjustable inductor is represented on circuit diagrams.

d. *Variable inductors* are found principally in the antenna circuits of radio transmitters. They usually consist of two coils connected in series, and are so constructed that one coil may be rotated within the other and the inductance consequently varied. Such inductors are called *variometers*.

MOVING COIL

FIXED COIL

SHAFT

Symbol:

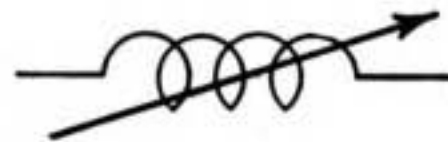


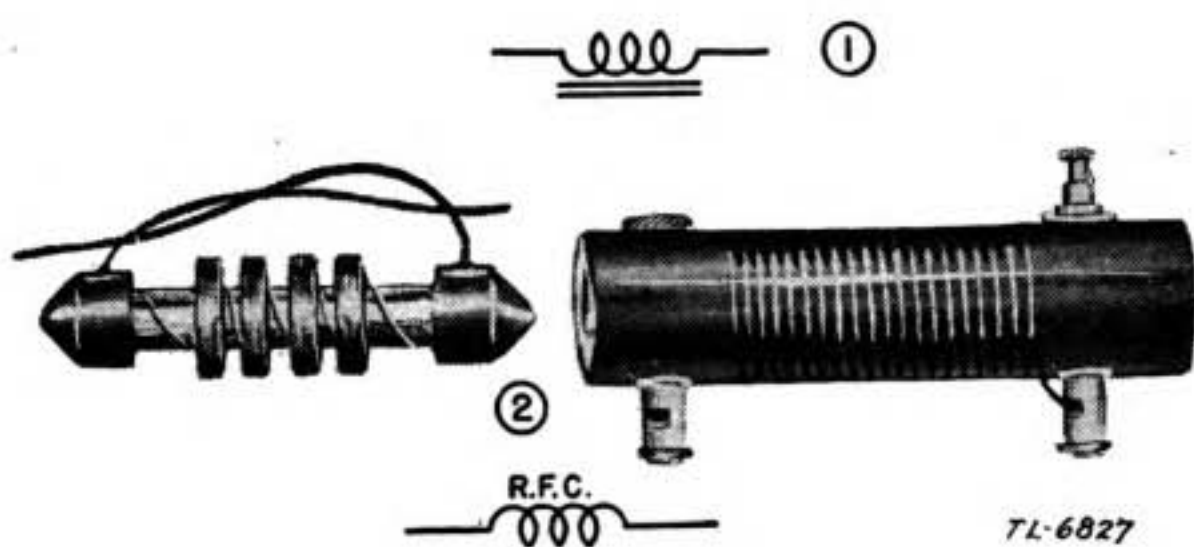
Figure 13. Variometer.

Figure 13 shows a typical variometer and gives the symbol for representing variable inductors on circuit diagrams.

e. A *choke coil* is a fixed inductor possessing the desirable property of showing a high reactance to the flow of alternating current, while showing a very low resistance to the flow of direct current. Thus, a choke coil will easily pass direct current but will try to block or "choke" off the passage of alternating current. Very small air-core choke coils are used to prevent r-f alternating current from flowing in d-c circuits. Large iron-core choke coils are used in a-f circuits, and as filter chokes in power supply circuits. Figure 14② shows two small r-f choke coils and their symbol. An iron-core filter choke is also shown, with its appropriate symbol, in figure 14①.

12. Transformers

a. If two coils are placed near to each other so that the field created by one coil will pass through the windings of the other, a transformation effect will result, since one coil transfers energy from itself to the

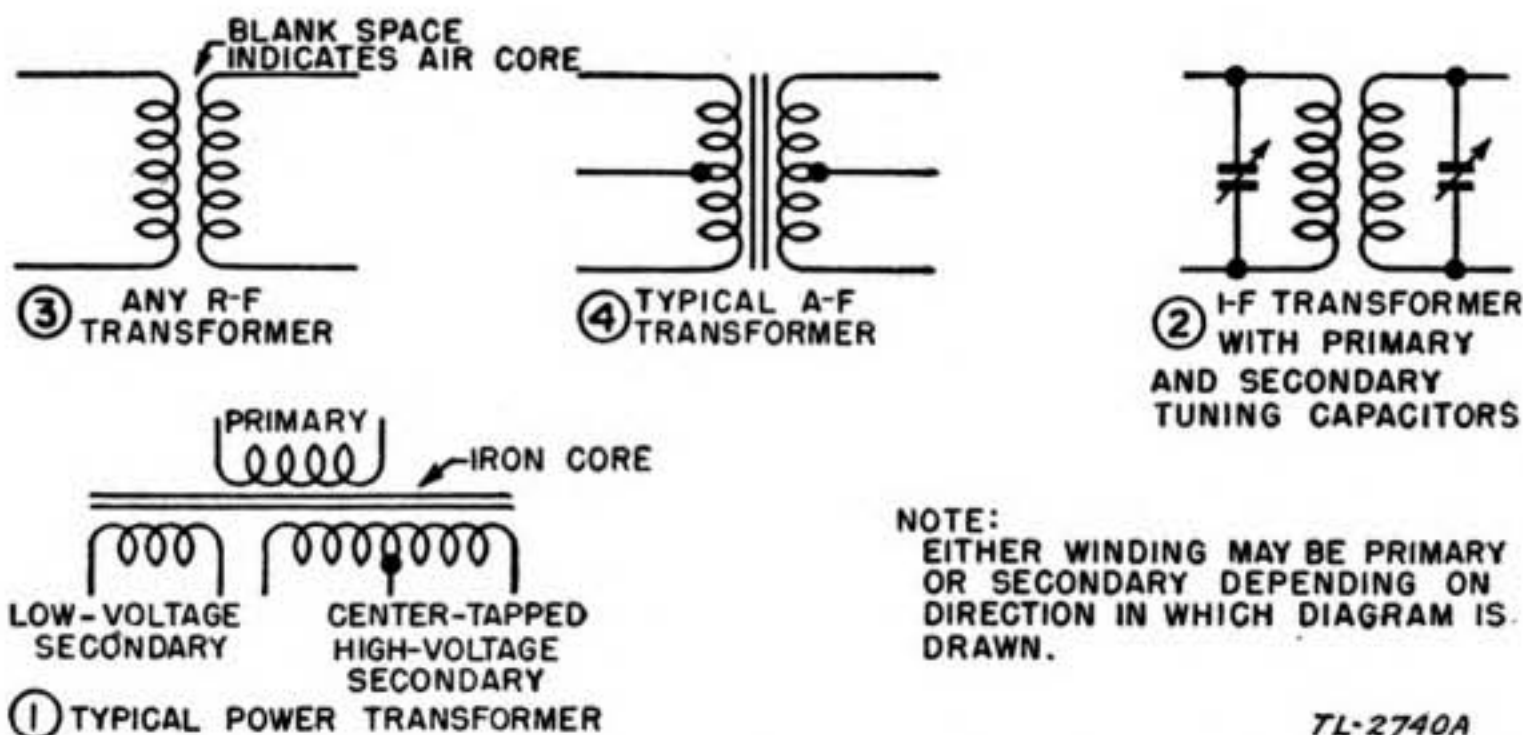


- ① *A-f filter choke.*
 ② *R-f chokes.*

Figure 14. Choke coils.

other coil. For example, if one coil has an a-c generator connected to it, the varying lines of magnetic force from the one coil will cut through the second winding, causing a voltage to be induced (or originated) in the second coil, even though there is no metallic connection between the windings. The coil producing the original magnetic field (or lines of force) is called the *primary*, and the coil in which the voltage is induced is the *secondary*; the two coils in inductive relations to each other are called a *transformer*. In radio there are three general groupings of transformers according to application: *power transformers*, *a-f transformers*, and *r-f transformers*. The power and a-f transformers have cores of magnetic materials, usually some form of iron. The r-f transformers are generally of air-core design. However, very small magnetic cores, usually consisting of powdered iron, are used in some low-frequency r-f transformers, known as *intermediate-frequency (i-f) transformers*. Several different types of transformers with their corresponding circuit diagram symbols are shown in figures 11 and 15.

b. Power transformers used in radio receivers and transmitters transform the line voltage (usually 110–120 volts) to either higher or lower voltages. When the voltage is raised the transformer is called a step-up transformer; when the voltage is reduced the transformer is called a step-down transformer. Power transformers having both



- ① Multi-winding power transformer. (Leads from the various windings protrude through holes in bottom of case.)
- ② I-f transformer, with attached midget variable air capacitors for tuning the primary and secondary windings. (This assembly fits inside the square aluminum can 2₁.)
- ③ R-f transformer. (This assembly is mounted in the round aluminum can 3₁.)
- ④ A-f transformer of push-pull output type.

Figure 15. Typical transformers.

step-up and step-down windings on the same core are widely used; such a transformer is shown in figure 15①.

c. *Audio-frequency transformers* are used to transfer voltages of wide a-f range, rather than voltages of a single frequency, as in the case of a power transformer. A-f transformers have iron cores, and must be able to carry a limited amount of direct current in the primary windings without effecting a-c audio frequency. A typical a-f transformer is shown in figure 15②.

d. Radio-frequency transformers are used to transfer r-f voltages, and are usually designed to operate on one particular frequency. Receiver transformers are quite small in size, and generally have air cores (figs. 11③, ④, and ⑤, and 15③).

e. When r-f transformers are used for transferring radio frequencies which are low compared to the signal frequency (as in the case of a superheterodyne receiver, which will be discussed later), the device is known as an *intermediate-frequency (i-f) transformer* (fig. 15④). I-f transformers operate on a single frequency, and may have powdered iron cores.

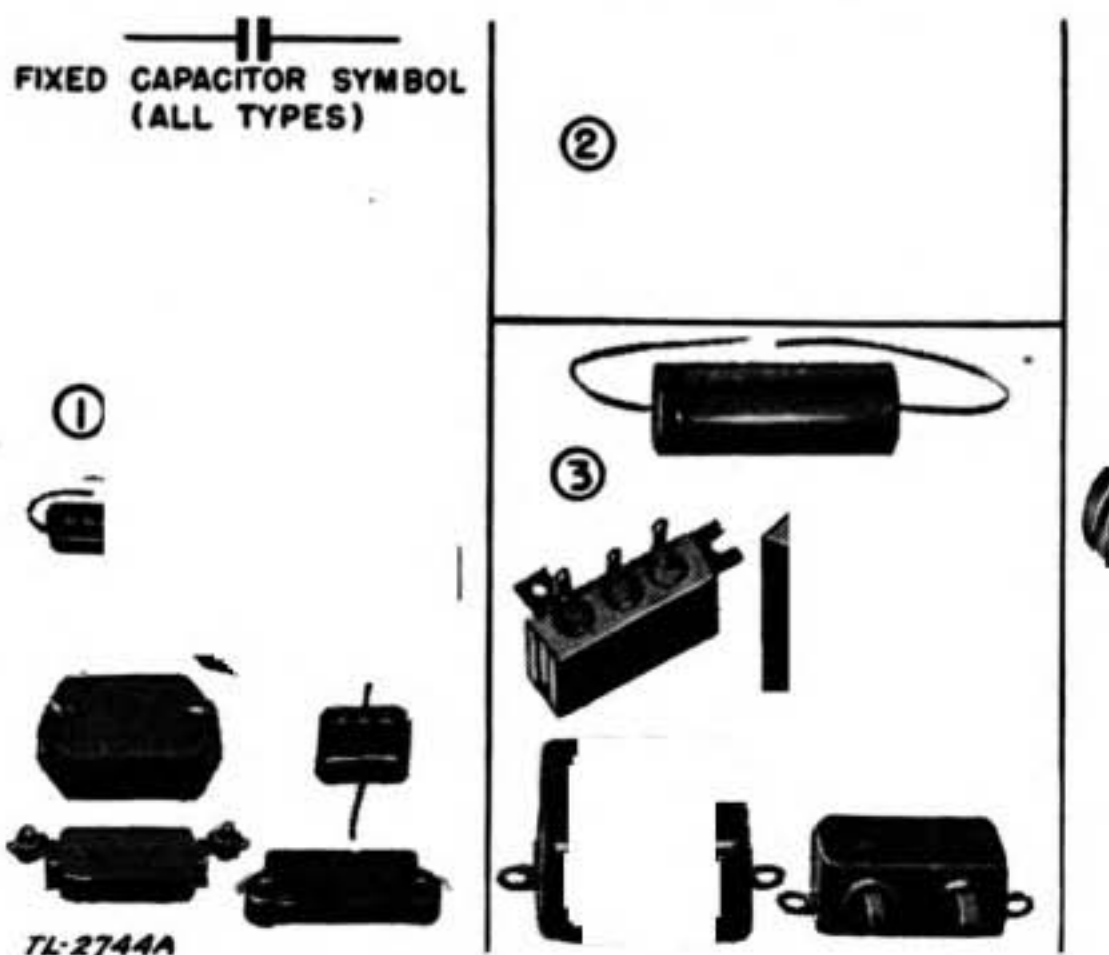
f. Autotransformers consist of only a single coil. It is possible to obtain transformer action with such a coil if a connection is made somewhere along the winding between the extreme ends. If a step-up voltage effect is desired, the winding between the tap and one end is considered the primary, and the entire winding acts as the secondary. If a step-down effect is desired, the entire winding is considered the primary, and the section between the tap and one end acts as the secondary. Autotransformers are used in power circuits.

13. Capacitors

a. A *capacitor* is a circuit element designed to introduce capacitive reactance in a circuit. In radio work the units of capacitance are the *microfarad* (abbreviated μf or mf) and the *micromicrofarad* (abbreviated $\mu\mu\text{f}$ or mmf). One microfarad is equal to 1,000,000 micromicrofarads. A capacitor is formed by two or more metallic plates separated by an insulating material called a *dielectric*. The capacitance of a capacitor is increased as the area of the plates is increased; the capacitance is decreased, however, as the distance between the plates is increased. The capacitive reactance becomes smaller as the capacitance is increased. This is just the opposite of what happens in the case of the inductor, where the inductive reactance increases as the inductance is increased. If an ordinary battery is connected to the two terminals of a capacitor, the capacitor will become charged and will hold the charge for a length of time depending on the insulating material used for the dielectric. If the dielectric is an excellent insulator, the capacitor will hold the charge for a long time, and is then said to have low *leakage*. There are three general types of capacitors: *fixed*, *adjustable*, and *variable*.

b. Fixed capacitors have a fixed value of capacitance in a circuit, and the majority of the capacitors used in radio are of this type. Many types of construction are found, depending chiefly on the voltage rating desired and the amount of leakage permissible in the dielectric. Fixed capacitors are generally named after the type of dielectric used in the construction. The main types of fixed capacitors are: *mica capaci-*

tors, paper capacitors, and electrolytic capacitors. These different types of fixed capacitors are shown in figure 16.

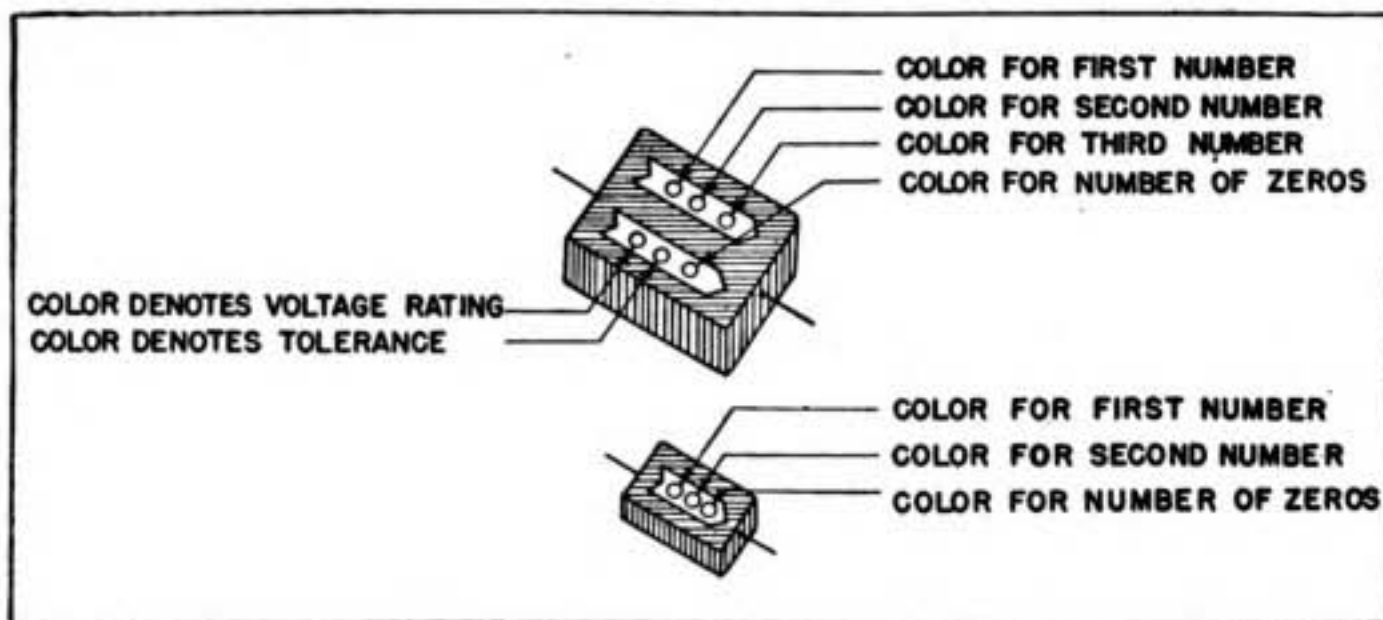


- ① Mica dielectric.
- ② Paper dielectric, oil-impregnated.
- ③ Paper dielectric, wax-impregnated.
- ④ Electrolytic.

Figure 16. Typical fixed capacitors.

c. Mica capacitors are used mainly in the r-f circuits of transmitters and receivers. Low leakage is an important requirement of such circuits. Therefore, mica is used as the dielectric, because it is one of the best known insulating materials. Mica capacitors are seldom found with capacitance values greater than 0.05 microfarad, and they generally have high voltage ratings. Mica capacitors, like fixed resistors, are often color-coded to indicate their value of capacitance. (A complete explanation of the mica capacitor color code is given in table IV.)

Table IV. Mica Capacitor Color Code.



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<i>Color</i>	<i>Number</i>
Black	0
Brown	1
Red	2
Orange	3
Yellow	4
Green	5
Blue	6
Violet	7
Gray	8
White	9
Gold	5 percent accuracy
Silver	10 percent accuracy

NOTE. All values of capacitance are given in micromicrofarads. All voltage ratings are expressed in hundreds of volts.

d. Paper capacitors consist of tinfoil and paper rolled together and impregnated with wax to exclude moisture. They are widely used in circuits where extremely low leakage is not important, such as a-f amplifier circuits, power supply circuits, and some r-f amplifier circuits.

e. Electrolytic capacitors depend on a chemical action within them to produce a very thin film of oxide as the dielectric. Consequently, these capacitors are polarized; that is, they have a positive and a negative terminal which must be properly connected in a circuit. Improper connections will damage the oxide film and short the capacitor. Since these capacitors depend on a chemical action which takes place when current flows through them to produce their dielectric, electrolytic capacitors have much higher leakage than either mica or paper capacitors. The principal advantage of electrolytic capacitors is that, for their size, they have a much larger capacitance than the other forms of capacitors. They are used chiefly in power supplies where leakage is not important.

f. Adjustable capacitors are used wherever it is necessary to adjust the capacitance of a circuit from time to time. These adjustable capacitors are sometimes known as *trimmers*, and are widely used for very fine adjustments of the tuning of a radio receiving set (known as



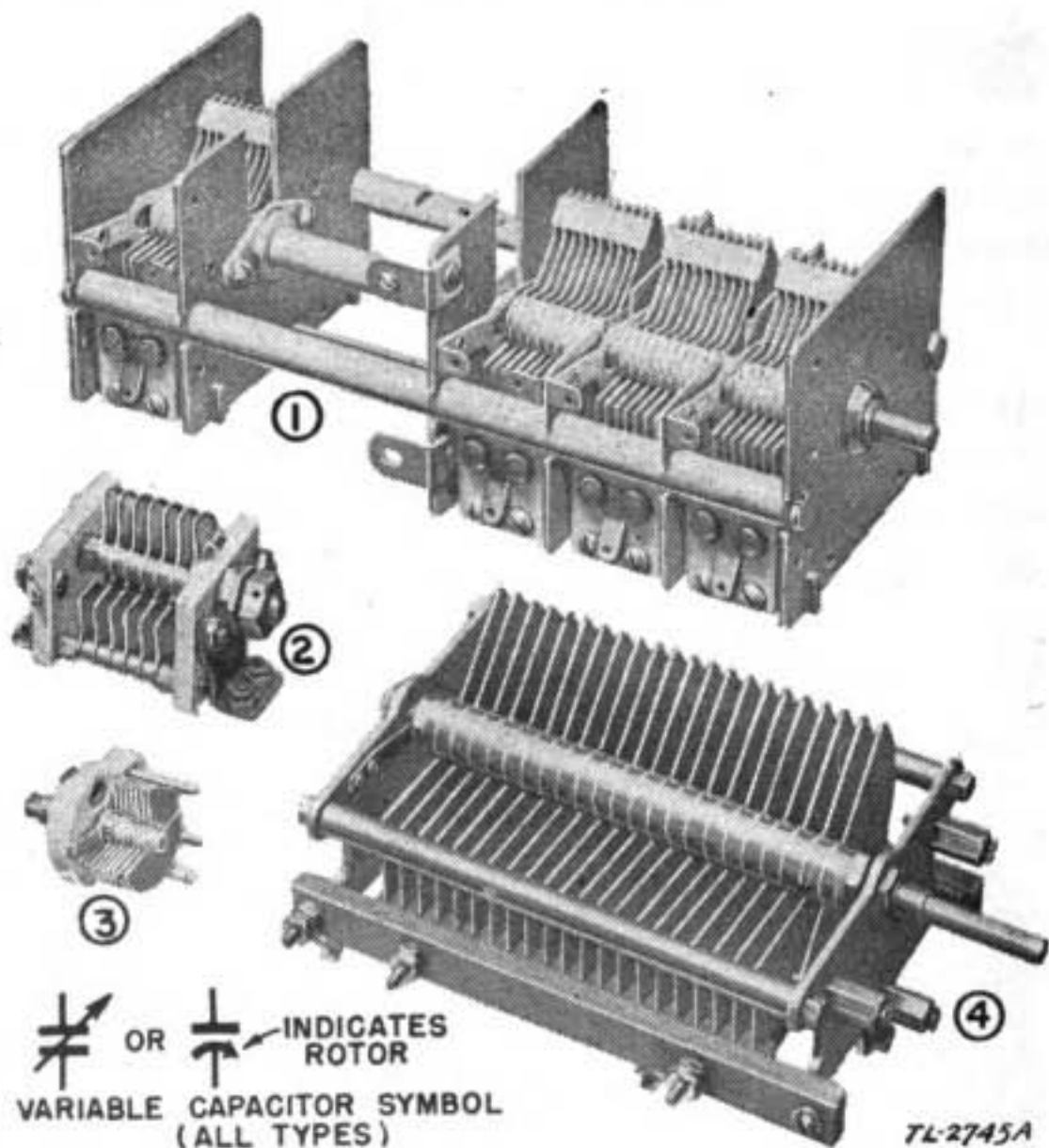
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- ① *Air-tuned.*
 ② *Mica-tuned.*

Figure 17. Trimmer capacitors.

aligning). They are also often used for tuning circuits which operate on only one frequency. Adjustable capacitors, or trimmers, are of two types: mica-tuned or air-tuned, according to the dielectric employed. Figure 17 illustrates both types of trimmers.

g. Variable capacitors are used in a circuit wherever the capacitance of a circuit must be continuously variable. They are used as tuning controls in practically all radio receivers and transmitters. Most variable capacitors used in communication circuits are of the air dielectric type. A single variable capacitor consists of two sets of metal plates insulated from each other and so arranged that one set of plates can be moved in relation to the other set. The stationary plates are the stator; the movable plates, the rotor. If several variable capacitors are connected on a common shaft so that all may be controlled at the same time, the result is known as a *ganged capacitor*. The capacitance range of variable air capacitors is from a few micromicrofarads to several hundred. A typical group of variable capacitors is shown in figure 18, with the appropriate symbols for this circuit element.



- ① *Four-gang receiving type.*
- ② *H-f transmitting type.*
- ③ *Trimmer, or padder type.*
- ④ *High-power transmitting type.*

Figure 18. Typical variable capacitors.

h. The principle of bypass and blocking capacitors is important for an understanding of the action of a capacitor in any circuit. Although a

capacitor due to the insulating properties of its dielectric, will not allow direct current to flow in a circuit, it will pass alternating current, since the capacitor charges and discharges in accordance with the frequency of the applied a-c voltage. The higher the frequency, the lower the reactance, and therefore the greater the current flow through the capacitor. This effect is just the opposite of that of the choke coil, which passes direct current, but presents a high reactance to the flow of alternating current. In some circuits, alternating current should not flow through a particular circuit element. By connecting a capacitor across (in parallel with) that element, a path of low opposition for the alternating current is provided; this bypasses the alternating current around the element while either the direct current or the low-frequency (l-f) alternating current flows through the element. In still other cases, no direct current should flow through a particular part of the circuit. A capacitor is therefore connected in series with the circuit, thus blocking the flow of direct current while allowing the comparatively free passage of the alternating current.

i. The voltage ratings of capacitors are of much the same importance as the power ratings for resistors. In addition to their capacitance, capacitors are rated as to their d-c working voltage, which is the maximum safe operating voltage for the capacitor. Under no circumstances should a capacitor be used in a circuit in which the voltage may exceed the rated working voltage. The safest rule to follow when replacing a defective capacitor in a radio set is to use a capacitor the working voltage of which is at least $1\frac{1}{2}$ times as great as the highest voltage expected in the circuit.

14. Capacitance Calculations

a. To make replacement repairs in the field, it is necessary to know how to determine the capacitance of capacitors when connected in series and in parallel, since, as in the case of resistors, a capacitor of exactly the right value may not be available.

b. For capacitors in series, the total amount of capacitance is found in exactly the same way as for resistors in parallel.

$$\frac{1}{C \text{ (total)}} = \frac{1}{c_1} + \frac{1}{c_2} + \frac{1}{c_3}.$$

Example: Determine the total capacitance of the following three capacitors connected in series: 200 μf , 100 μf , and 400 μf .

$$\begin{aligned} \frac{1}{C} &= \frac{1}{200} + \frac{1}{100} + \frac{1}{400} \\ &= \frac{2}{200} + \frac{4}{400} + \frac{1}{400} = \frac{7}{400} \\ C &= \frac{400}{7} = 57 \text{ microfarads.} \end{aligned}$$

The d-c working-voltage rating for capacitors in series is equal to the sum of the ratings of the individual capacitors.

c. For capacitors in parallel, the total amount of capacitance is found by adding the values of each of the capacitors. This is the same rule as for resistors in series.

$$C \text{ (total)} = c_1 + c_2 + c_3$$

Example: Determine the total capacitance of the following capacitors connected in parallel: 0.0005, 0.001, 0.0001, and 0.01 microfarad, respectively.

$$C = 0.0005 + 0.001 + 0.0001 + 0.01 = 0.0116 \text{ microfarad.}$$

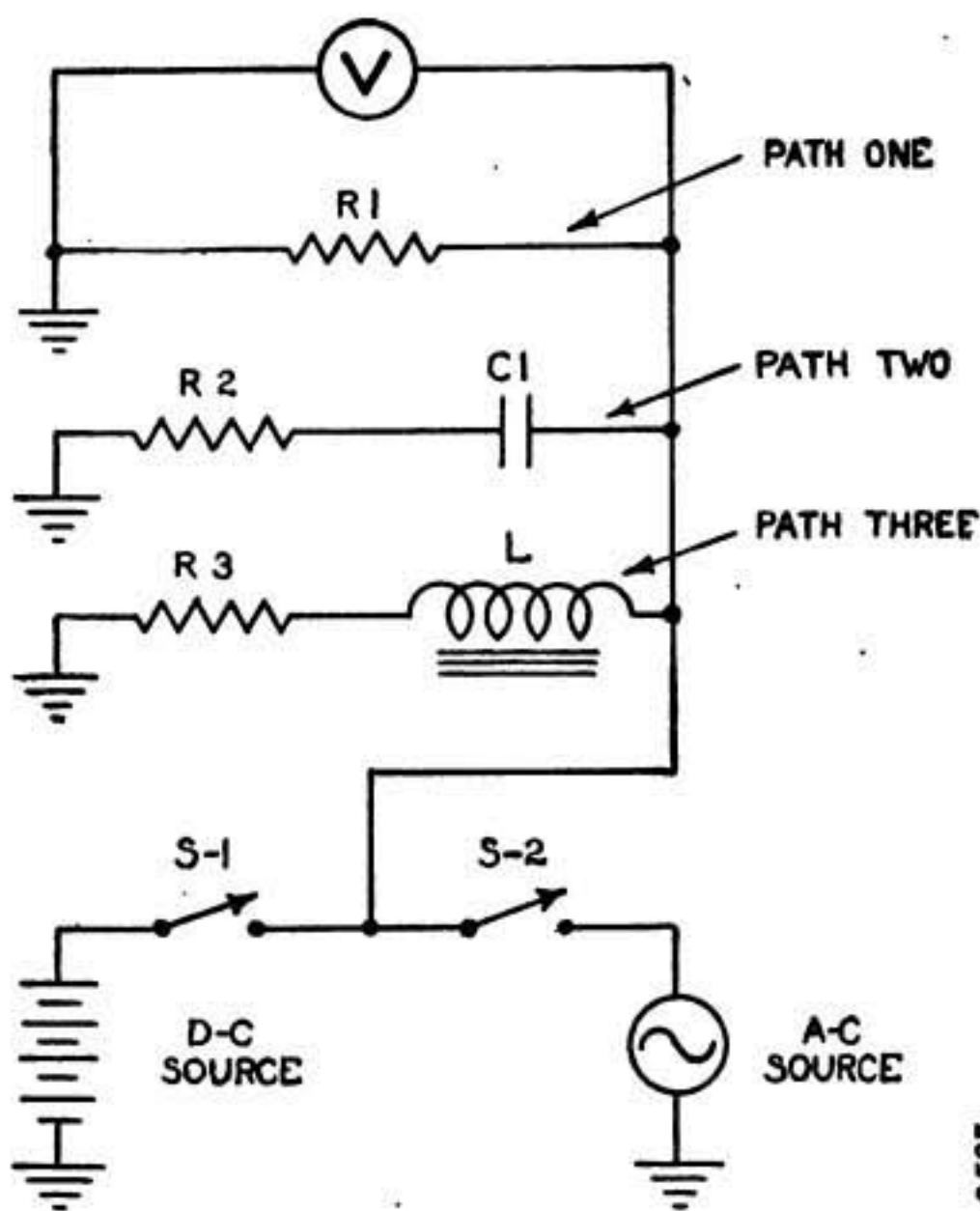
The d-c working-voltage rating of a combination of capacitors in parallel is equal to that of the capacitor with the *lowest* working-voltage rating.

15. Operation of Circuit Elements

a. Following the study of the individual properties and characteristics of the three circuit elements, *resistance*, *inductance*, and *capacitance*, it will now be shown how these circuit elements operate in an actual circuit. Figure 19 shows a circuit containing all three circuit elements, so arranged that if switch S-1 is closed, direct current will be applied to the circuit, and if switch S-2 is closed, alternating current will be applied to the circuit. The *ground* symbol shown on the diagram indicates that all points in the circuit so marked with this symbol are connected to a metal *chassis*, or base, on which the circuit is constructed; thus, all points bearing the ground symbol are actually connected together (via the metal in the chassis). This chassis ground symbol is used quite frequently in circuit diagrams to indicate that a part or a circuit element is connected to the chassis. The symbol does not necessarily mean that the part is actually connected to an *earth ground*, although it is sometimes used in this way in transmitter and receiver circuits, as will be shown later.

b. In studying the circuit of figure 19, it will be seen that there are three possible paths through which current may flow. The first is through resistor R1 and back through ground (or the chassis) to whichever power source is in use; the second is through capacitor C1 and resistor R2 and back through ground; the third is through inductor *L* and resistor R3 and back through ground. It will be assumed that inductor *L* has a large inductance, and that capacitor C1 has a large value of capacitance. Note that all three paths are connected in *parallel*.

c. The first step in the study of this circuit is to close switch S-1, applying *direct current* to the circuit. Current will flow through resistor R1, the first path; the amount of current which flows through



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Figure 19. Operation of circuit elements.

this path will depend on its resistance. No current will flow in the second path since the *dielectric* of capacitor C acts as an *insulator*, and thus the capacitor will *not* pass direct current. Although no current is flowing in the second path, voltmeter V , which is connected across all three paths in parallel, indicates that there is a voltage present across R_2 and C_1 . Also, if the voltmeter were placed across C_1 , the same value of voltage would be found across it, since there is no current flowing in this path, and consequently, there is no voltage drop across R_2 . This example shows that it is possible for a voltage to be present in a circuit, *even though the circuit is open* (that is, there is no flow of current). Current will flow in the third path, since the only opposition to current flow in this branch of the circuit is the d-c resistance of the coil windings of inductor L and the resistance of resistor R_3 . The amount of current flow will be determined by the total resistance in this path; that is, *the sum of the d-c resistance of L and the resistance of R_3 .*

d. The next step in the study of this circuit is to open switch $S-1$ and close switch $S-2$, applying alternating current to the circuit. When this is done, current will flow through resistor R_1 in the first path. Since a resistor offers the same opposition to alternating current as to direct current, the current flowing in this path will be the same

regardless of whether alternating current or direct current is applied to the circuit. In the second path, through capacitor $C1$ (which has a large value of capacitance) and resistor $R2$, conditions will be similar to those in the first path. Due to its large capacitance, $C1$ will present a small reactance to the flow of current through this branch of the circuit. Thus, the impedance of this second path, or its *total opposition* to the flow of alternating current, being due to both the *small* reactance and the resistance, will be, for practical purposes, about equal to the resistance $R2$. In path three of the circuit, inductor L has such a large value of inductance, that it will present a high reactance to the flow of alternating current. The impedance of this path, which is due to both the large reactance and the resistance, will be so high that the current flow through $R3$ and L will be extremely small.

e. To sum up the effects of the circuit elements on both alternating current and direct current, both switches are closed to apply alternating current and direct current to the circuit at the same time. The important results then will be: In path one, both alternating current and direct current will flow; in path two, only alternating current will flow; in path three, a relatively large value of direct current will flow, but only a very small value of alternating current will flow. Thus it can be seen from this study that with both alternating current and direct current present in a circuit, the current flow of either may be permitted, stopped, or restricted, by the proper choice of circuit elements.

16. Audio-frequency Circuit Elements

a. The instruments and devices used to change sound waves into electrical (audio) frequencies, and vice versa, are important parts of the complete radio transmitter and receiver.



Figure 20. Carbon microphone T-17.

b. A *microphone* is a circuit element for converting sound (acoustical) energy into electrical (audio) energy. The various types of microphones are named in accordance with the methods used to produce this conversion, or change. Thus, there are carbon, condenser, dynamic, velocity, and crystal microphones. *Carbon microphones* use the variation of resistance between loosely packed carbon granules (due to acoustical or sound pressure in a diaphragm) to vary the electrical current at an audio-frequency rate. An Army microphone (Microphone T-17) is shown in figure 20. *Condenser microphones* operate on the principle of sound energy causing a variation in the spacing between two plates which act exactly like a capacitor; the resulting variation of capacitance (due to the movement in and out of the plates) causes a variation at audio frequencies. *Dynamic microphones* use a low-impedance coil mechanically coupled to a diaphragm; sound waves move the diaphragm and the coil, and the movement of the coil in a magnetic field causes currents in the coil at audio frequencies. The *velocity microphone* also operates on the electro-magnetic principle, but uses a ribbon of dural (a metal alloy) suspended between the poles of a powerful magnet. When the ribbon is vibrated by acoustical energy, it cuts the lines of force, and a current, which varies in accordance with the sound waves, is induced in the ribbon. One type of *crystal microphone* uses a Rochelle salt crystal fastened to a diaphragm. When sound waves move the diaphragm, the crystals vibrate and produce an alternating voltage between the crystal electrodes at the frequencies of the sound waves. All of the types mentioned (except the crystal microphone) require either some source of current, a magnetic field, or a polarizing voltage.

c. *Headsets and loudspeakers* are circuit elements for converting electrical (a-f) energy into sound (acoustical) energy. In general, the



Figure 21. Headset.

Table V. Tabulation of common radio symbols.

Device	Symbol	Device	Symbol	Device	Symbol
Conductor or Wire		Cable, Shielded		Coil or Inductor, Tapped	
Crossed wires — top, connection; bottom, no connection		Resistor, Fixed		Coil or Inductor, Iron Core	
Ground		Resistor, Variable		Coil or Inductor, Powdered Iron Core	
Antenna		Capacitor, Fixed		Transformer, Powdered Iron Core	
Counterpoise		Capacitor, Fixed, Shielded		Transformer, Air Core	
Antenna, Loop		Capacitor, Variable		Transformer, Variable Coupling, moving coil shown	
Terminals		Capacitor, Variable, moving plates shown		Transformer, Iron Core	
Shielding		Capacitor, Variable, Shielded		Transformer, Air Core, Tuned	
Wire, Shielded		Capacitors, Variable, Ganged		Inductors, Link Coupled	
Wire, Twisted Pair		Capacitor, Dual Section		Key	
Cable, Coaxial		Coil or Inductor		Switch, Single Pole, Double Throw	
Wire in cable		Coil or Inductor, Variable		Switch, Rotary	

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headset or the loudspeaker performs the opposite function of a microphone. When varying (a-f) currents flow through the windings on the permanent magnet of a headset, the diaphragm vibrates in accordance with these currents and thus produces audible sound waves proportional to the variations of current. A typical headset is shown in figure 21, with the circuit diagram symbol. One type of loudspeaker works on much the same principle as the headset; but instead of a metal diaphragm, the loudspeaker uses a paper cone, moved by a small armature, for setting up audible sound waves. Figure 22 shows a loudspeaker of this type removed from its cabinet.

Table V. Tabulation of common radio symbols—Continued.

Device	Symbol	Device	Symbol	Device	Symbol
Switch, Double Pole, Double Throw		Connector, Male (typical)		Envelope or Shell	
Selector Switch (typical)		Connector, Female (typical)		Envelope, Gas Filled	
Switch, Power		Dry Cell or Battery		Beam Tetrode Vacuum Tube	
Relay (typical contact arrangement)		Headset		Vacuum Tube, Voltage Regulator	
Jacks		Loud Speaker		Vacuum Tube, Triode, Octal Base	
Plug, Microphone, Headset or Speaker		Microphone		Vacuum Tube, Triode, Octal Base	
Plug for power outlet		Cathode, Thermionic		Vibrator	
Power Receptacle or Outlet		Cathode, Cold Discharge		Crystal	
Connector, Polarized, Male		Filament		Oxide Rectifier	
Connector, Polarized, Female		Grid		Fuse	
Connector, Twistlock, Female		Plate or Anode		Lamp or Pilot Light	
Connector, Polarized, 2-Wire, Male		Beam Forming Electrodes		Voltmeter	

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17. Insulators

In addition to the metal materials which conduct electricity very readily (such as copper and iron), it is often necessary to have other materials which offer a very high resistance to the flow of current, in order to prevent the electricity from "straying away" at points where physical support is essential. Such materials are known as *insulators*. While a perfect insulator does not exist, there are some materials, such as porcelain, glass, and ceramic materials, which effectively prevent any leakage. It is important to note that insulators which are satisfactory for power purposes may not be suitable for radio work. In radio circuits which operate with microwatts of energy, any minute

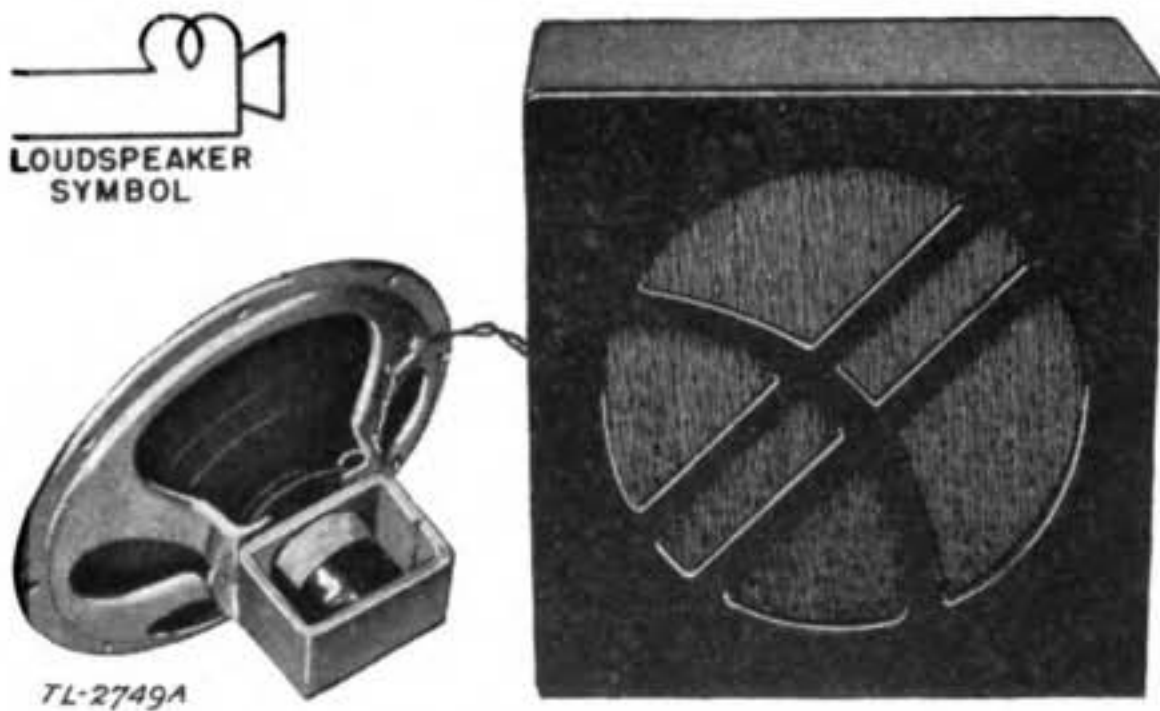


Figure 22. Permanent magnet loudspeaker and cabinet.

leakage of current is of definite concern. The dielectric bars which insulate the stator plates from the frame of a variable air capacitor must be kept clean to prevent any stray leakage. Any slight leakage currents on insulator surfaces, such as tube bases and sockets, are also important. In general, it is well to keep radio insulators away from strong electric fields, and to maintain all insulators dry and clean.

18. Symbols

a. It is not practical to show radio circuit diagrams in the form of photographs or drawings of the actual parts or components, since only the outer appearance of the parts would be shown, leaving the inner workings obscure. Therefore, in radio circuit diagrams (also known as schematic diagrams) special symbols are used to represent the various circuit elements and parts, in order to simplify the drawings. Symbols for the various types of resistors, inductors, and capacitors have already been introduced, and a complete list of all commonly used symbols is given in table V. The student should refer to this list whenever in doubt about the identification of any part of a circuit diagram.

b. The more common symbols explain themselves by their own appearance, but some may cause confusion. An arrow point, for example, may have varied meanings. At the end of a line which seems to be continuing out from the schematic diagram, the arrow point signifies that there is more of the circuit than is shown. Arrows along circuit lines may indicate the direction of the signal current through the apparatus. If the arrow point rests against a piece of equipment it probably means that there is a contact which is capable of movement or adjustment. Finally, an arrow drawn diagonally through any other symbol means that the device is adjustable smoothly and continuously, as, for example, a variable resistor or a variable inductor.

SECTION III

TUNED CIRCUITS

19. General

a. Tuned circuits are combinations of circuit elements so arranged that they produce a desired effect in the radio circuit. Both transmitters and receivers depend on tuned circuits for their operation on the desired frequency. And if it were not for tuned circuits operating in conjunction with vacuum tubes, modern radio would not be possible.

b. In radio receivers tuned circuits are necessary not only for the selection of desired signals, but also for the rejection of undesired signals. The ability of a receiver to select the desired frequency while rejecting the undesired frequencies is called *selectivity*. The selectivity of a receiving set is entirely dependent on the proper operation of its tuned circuits. If the tuned circuits are not functioning properly, if they are improperly tuned, or if any of the parts of which they are constructed are defective, then the sensitivity of the set (ability to receive weak signals) will either be considerably reduced or the receiver will not work at all.

c. In radio transmitters, not only are tuned circuits depended on for operation on the desired frequency, but the entire process of r-f power generation and amplification is dependent on the proper functioning of tuned circuits. If the tuned circuits of a radio transmitter are not operating properly due to a defective part or if they are incorrectly tuned, the power output of the transmitter (and consequently the transmission range) will either be considerably reduced or the transmitter will become entirely inoperative.

20. Curves and Graphs

In radio work, curves and graphs are widely used to show the operation of parts and circuits, because a single curve or graph will explain the operation of the part or circuit more simply than a long description in words. A curve or graph gives a picture of what is happening to one value in a circuit as another value is changed. Curves and graphs used in newspapers and magazines, showing business trends or changes in the population over a period of time, are all familiar. The curves and graphs used in radio work are constructed and read in

exactly the same manner. They can show the voltage in a circuit in relation to frequency, the reactance of a circuit element in relation to frequency, or the voltage in a circuit in relation to current. For example, in section II it was shown that the reactance of a capacitor decreases as the operating frequency is increased. This relationship can be shown

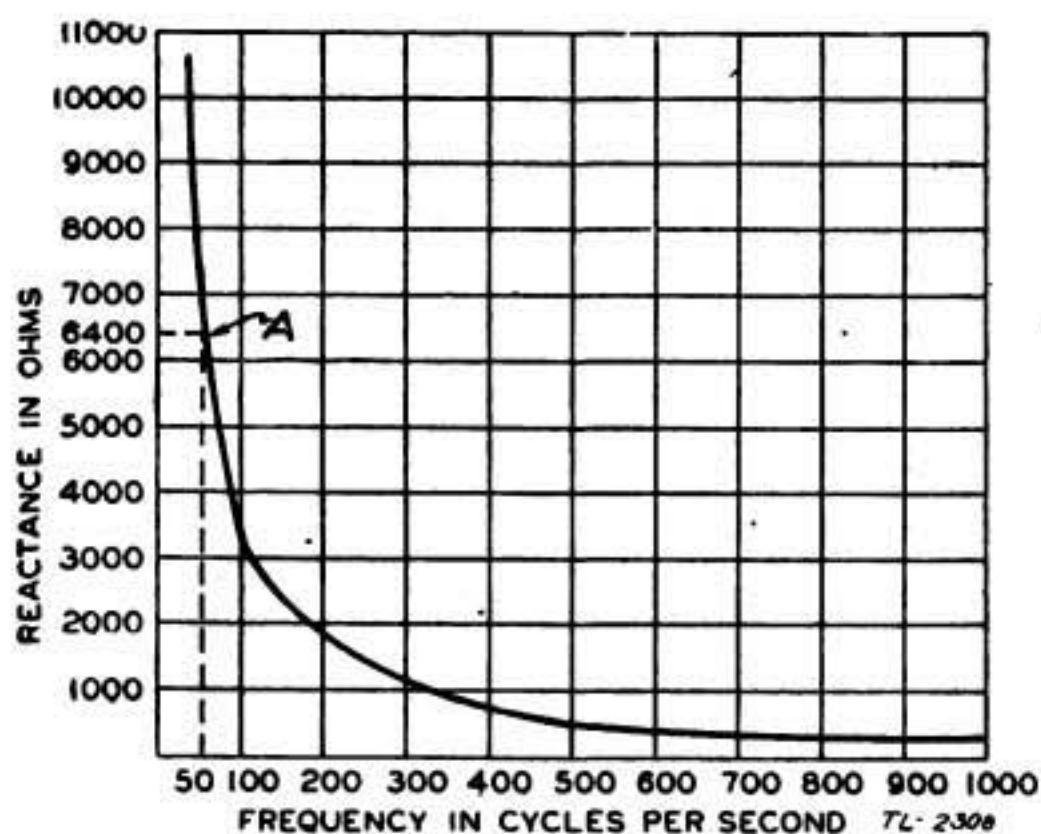


Figure 23. Graph showing reactance of $0.5 \mu\text{f}$ capacitor from 30 to 1,000 cycles per second.

on a graph, illustrated in figure 23. Each point on this graph shows the value of reactance of the capacitor for a different frequency. Point A shows that the reactance of the capacitor is approximately 6,400 ohms at a frequency of 50 cycles per second. Graphs will be extensively used in this section to indicate what happens in tuned circuits.

21. Resistance, Reactance, and Impedance

a. A resistor presents the same resistance to the flow of alternating current as it does to direct current. The opposition offered to the flow of alternating current by inductors and capacitors is called reactance. If a circuit contains both resistance and reactance, the total opposition offered to the flow of alternating current is called the *impedance* of the circuit. The impedance of a circuit is the *combined effect of resistance and reactance* in opposing the flow of alternating current. Impedance is measured in ohms.

b. The effect of inductive and capacitive reactance on current and voltage is of important concern in radio work. Inductive reactance, in addition to increasing as the frequency is increased, has another effect which plays an important part in tuned circuits: it not only opposes the flow of alternating current, but also causes it to lag a fraction of a cycle behind the applied voltage, as shown in figure 24. If a circuit contains only inductive reactance, the current will lag behind the

voltage by exactly one-quarter of a cycle, or 90° . Capacitive reactance has just the opposite effect: it causes the current to lead the voltage by

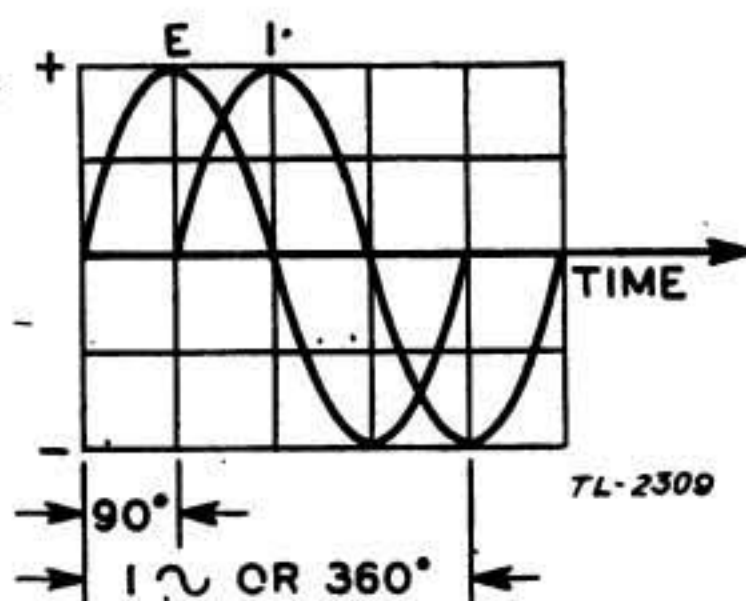


Figure 24. Effect of inductive reactance.

a fraction of a cycle, as shown in figure 25. If a circuit contains only capacitive reactance, the current will lead the voltage by 90° .

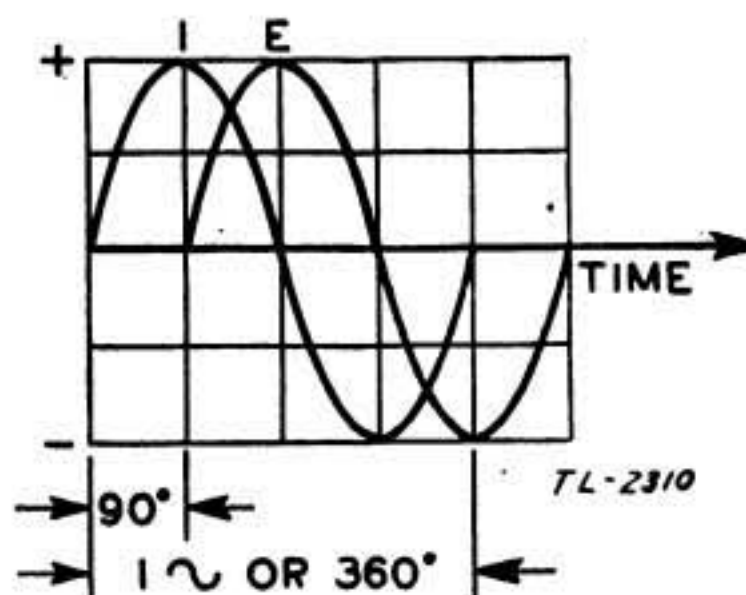


Figure 25. Effect of capacitive reactance.

c. Instead of referring to fractions of a cycle as one-half of a cycle, or one-quarter of a cycle, in radio work parts of a cycle are expressed in degrees: one full cycle equals 360° , one-half cycle equals 180° , or one-quarter cycle equals 90° , etc. If two voltages, or a voltage and a current, do not reach their maximum and minimum values at the same time in a circuit, the difference between the two is expressed in degrees. This effect is called the *phase shift*, or the phase difference. For example, if the current in a circuit either lags or leads the voltage by one-quarter of a cycle, or 90° it is said that the two are 90° out of phase, or that there is a phase shift of 90° . If the current and the voltage in a circuit reach their maximum and minimum values at exactly the same time, it is said that they are in phase.

d. Since inductive reactance causes the current to lag 90° behind the voltage, and capacitive reactance causes it to lead the voltage by 90° , it

can be seen that the difference in the two effects is 180° (or one-half of a cycle). Since one half of a cycle is positive and the other half is negative, a change of half of a cycle, or 180° , will represent a change in polarity. Therefore, the effect of inductive reactance can be considered as *positive reactance*, and capacitive reactance can be considered as *negative reactance*.

22. Reactance Calculations

a. Since inductive reactance is proportional to inductance and frequency, a simple formula can be used to determine the inductive reactance of a coil.

$$X_L = 2\pi fL$$

Where X_L = the amount of inductive reactance in *ohms*,
 L = the inductance of a coil in *henrys*,
and f = the frequency in cycles per second.

2π is a mathematical constant used a great deal in radio work; it is equal to about 6.28.

Example: Find the reactance of a coil of 5 henrys at a frequency of 60 cycles per second.

$$\begin{aligned} X_L &= 6.28 \times 60 \times 5 \\ &= 1,884 \text{ ohms of inductive reactance.} \end{aligned}$$

Example: Find the reactance of an inductance of 6 millihenrys at a frequency of 1,000,000 cycles per second.

$$\begin{aligned} X_L &= 6.28 \times 1,000,000 \times 0.006 \\ &= 37,700 \text{ ohms of inductive reactance.} \end{aligned}$$

It should be observed that inductances expressed in subdivisions of the henry must be converted into henrys before substituting in the formula for reactance.

b. Since the amount of energy stored in a capacitor (for a given voltage) is fixed by the actual capacity, the total amount of energy stored (and subsequently restored to the circuit) in 1 second will be greater when the capacitor is charged many times per second than when it is charged only a few times per second. Therefore, the current flow will be proportional to the frequency and to the capacitance of the capacitor, and the reactance will be inversely proportional to the frequency and the capacitance. The formula for capacitive reactance is—

$$X_C = \frac{1}{2\pi fC}$$

where X_c = the amount of capacitive reactance in ohms,
 C = the capacitance of a capacitor in farads,
 f = the frequency in cycles per second,
and 2π = about 6.28.

Example: Find the reactance of a 2-microfarad capacitor at 60 cycles per second.

$$X_c = \frac{1}{6.28 \times 60 \times 0.000002}$$

$$= 1,330 \text{ ohms of capacitive reactance}$$

It should be observed that capacitance in the above formula must be represented in farads.

23. Series Resonance

a. If a coil and a capacitor are connected in series with a variable-frequency source of alternating current (fig. 26), the combination of parts is called a *series-tuned circuit*, or a *series-resonant circuit*. Since the windings of the coil in such a circuit will produce a certain amount of resistance, the effect of this resistance must be considered in the operation of the circuit. This resistance is indicated in figure 26 as a resistor R . If the a-c source is set at a low frequency, it is found that the greatest opposition to the flow of current in the circuit is the reactance of capacitor C (since capacitive reactance increases as the frequency is decreased). If the a-c source is set at a high frequency, it is found that the greatest opposition to the flow of current is the reactance of inductor L (since inductive reactance increases as the frequency is increased). In other words, at low frequencies the reactance of the circuit is mainly *capacitive*, while at high frequencies the reactance is mainly *inductive*.

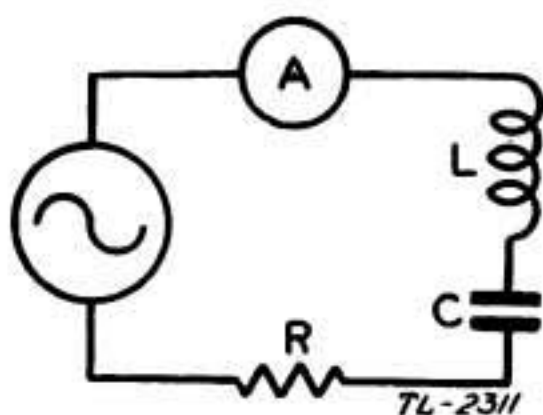


Figure 26. Series-resonant circuit.

b. At some frequency between the high and low extremes, the inductive reactance will be equal to the capacitive reactance. This frequency is known as the *resonant frequency* of the circuit, and it is said that the series circuit is tuned to this frequency. Since the inductive reactance in the circuit produces a positive effect, and the capacitive

reactance produces a negative effect, when they become equal in amount at the resonant frequency they cancel each other, so that the only opposition to current flow in the circuit is that offered by the resistor R .

c. The current flowing in the series circuit of figure 26 can be measured by means of meter A . If the source frequency is increased

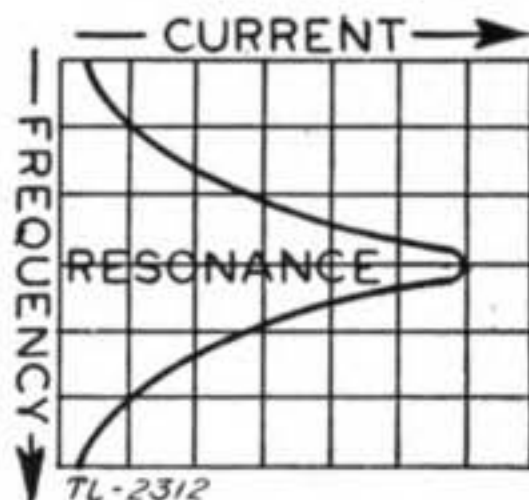


Figure 27. Current flow in series-resonant circuit.

gradually from a low to a high value, the current will rapidly increase until it reaches a maximum value at the resonant frequency, and then rapidly decrease, as shown by the graph in figure 27.

d. Since the current flow in a circuit is determined by the impedance of the circuit, the impedance of a series-tuned circuit is at its lowest,

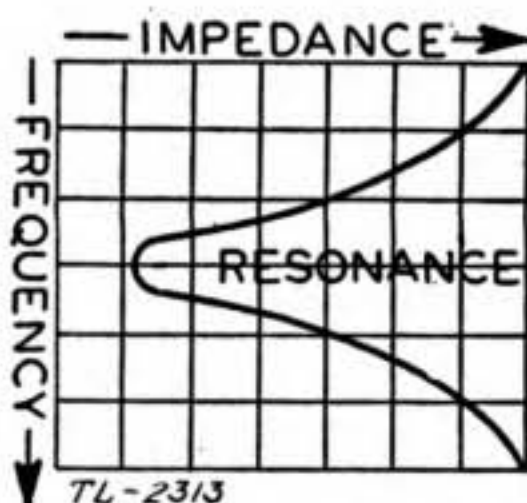


Figure 28. Impedance curve of series-tuned circuit.

or minimum value at the resonant frequency, and becomes greater on either side of the resonant frequency. (See fig. 28.)

e. Since the voltage drop across each element of a circuit will be proportional to the current flowing in the circuit and to the opposition offered by each element to the current flow, and since the current flowing in a series circuit is maximum at the resonant frequency, the voltage appearing across each of the elements in the circuit will also be greatest at resonance. Although the voltages across the coil and capacitor of the series circuit in figure 26 are equal in amount and opposite in polarity at the resonant frequency (and so cancel each other as far as the total circuit voltage is concerned), each of these voltages is very high. Either one of them can be used to operate other

radio circuits (such as vacuum tube circuits), since a very strong signal (amplification) can be obtained at the resonant frequency. This voltage amplification of radio signals at the particular frequency to which the circuit is resonant is one of the most important effects of tuned circuits.

f. A circuit is at resonance when the inductive reactance is of the same value as the capacitive reactance. If the value of either the coil or the capacitor is changed, the resonant frequency of the circuit is changed. If either the capacitance or the inductance is increased, or both of them are increased at the same time, the resonant frequency of the circuit is decreased. Conversely, if either the capacitance or inductance is decreased, or both of them are decreased at the same time, the resonant frequency is increased. Thus, by making either the inductor or capacitor in the circuit variable, the circuit can be tuned (or resonated) over a wide range of frequencies. The limits of the frequency range over which the circuit can be tuned will depend on the value of the fixed element, and the maximum and minimum values of the variable element. It is usually more convenient and more efficient to make the *capacitor* the variable element in a tuned circuit. For this reason variable capacitors, together with fixed inductance coils, make up the tuned circuits of practically all modern radio transmitters and receivers.

g. The resistance present in a resonant-tuned circuit determines the amount of selectivity of which the circuit is capable. Resonance curves for three different values of resistance (R in fig. 26) are shown in figure 29. These are the same type of curve as that shown in figure 27, where current is plotted against frequency at resonance. The resonance curves of figure 29 demonstrate the practicability of a tuned circuit as a selective device. The current flowing in a tuned circuit, when equal voltages of many different frequencies are applied to its terminals, is composed principally of frequencies equal to, or nearly equal to, the resonant frequency of the circuit. As resistance is added to the

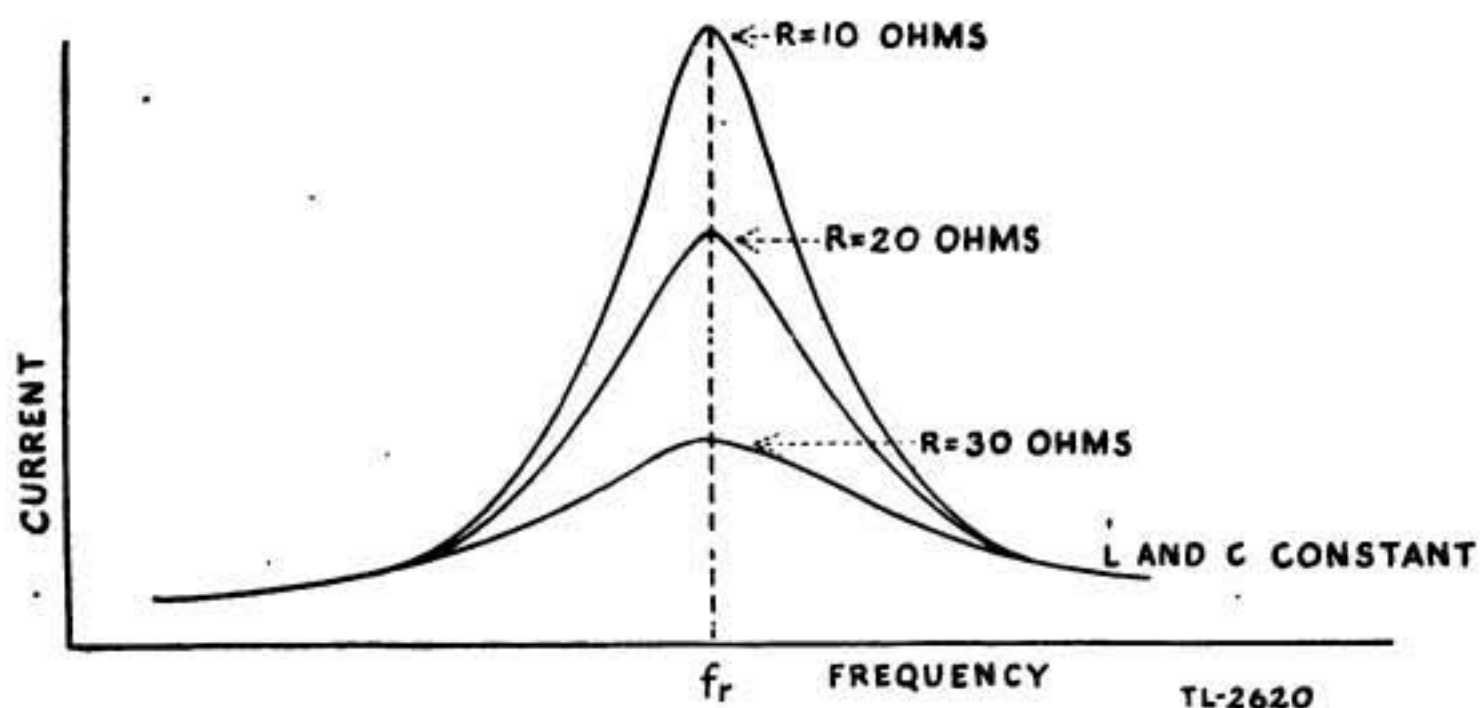


Figure 29. Resonance curves showing broadening effect of series resistance.

circuit, the current is attenuated in such a manner that a more nearly uniform but reduced resonance curve (or response) is obtained. Thus, resistance in the circuit acts to reduce the selectivity. It may also be shown that the effect of shunt resistance across either the inductor or the capacitor will likewise reduce the selectivity. Occasionally resistance is deliberately introduced into a radio circuit for the purpose of broadening the range of frequencies to which the circuit responds, although generally the inherent resistance of the circuit is more than enough for this purpose.

h. Series-tuned circuits are often used in the antenna systems of transmitters and receivers. They are particularly well suited to the antenna circuit requirements of transmitters, since maximum current flows in them at the resonant frequency. This means that maximum current will flow in the antenna at the desired operating frequency, and consequently there will be a maximum radiation of power at this frequency. Series-tuned circuits are also used as *wave traps*, or *filters* (see par. 26).

24. Parallel Resonance

a. If a coil and a capacitor are connected in parallel (fig. 30), the combination of parts is called a *parallel-tuned circuit*, or a *parallel-resonant circuit*. As in the series-tuned circuit of figure 26, whatever resistance may be present in the circuit because of the circuit elements is indicated on the diagram by the resistor *R*. Since the coil and capacitor of the parallel-tuned circuit are both connected across the line from the variable-frequency source of alternating current, there are two paths through which the current may flow: one path through the coil, and one path through the capacitor. If the a-c source is

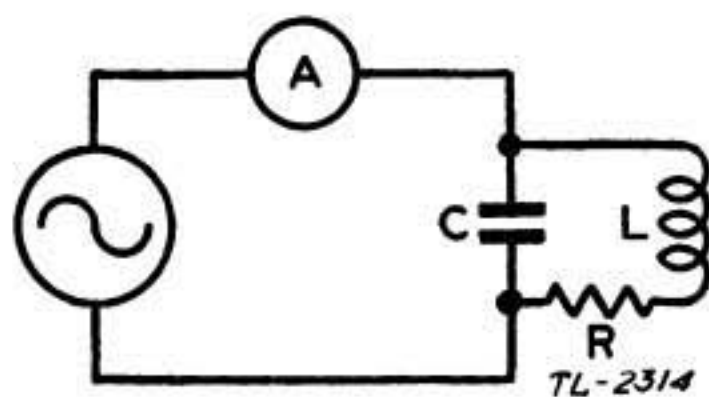


Figure 30. Parallel-resonant circuit.

set at a low frequency, most of the current will flow through the coil, since the reactance of the coil will be small for low-frequency alternating current, and the reactance of the capacitor will be high. If the a-c source is set at a high frequency, most of the current will flow through the capacitor, since its reactance will be small for high frequencies, while the reactance of the coil will be high.

b. At the resonant frequency, just as in the case of the series-tuned circuit, the reactance of capacitor C will be equal to the reactance of inductor L . However, unlike the series circuit, since the two circuit elements are in parallel, the current flowing through the inductive reactance (coil L) will be opposite in polarity to the current flowing through the capacitive reactance (capacitor C). Since the inductive reactance is equal to the capacitive reactance at the resonant frequency, the currents flowing through the two reactances will be equal in value as well as opposite in polarity, and consequently they will cancel each other.

c. The current flowing in the parallel circuit of figure 30 can be measured by the meter A . If the source frequency is varied from a low frequency through the resonant frequency to a high frequency,

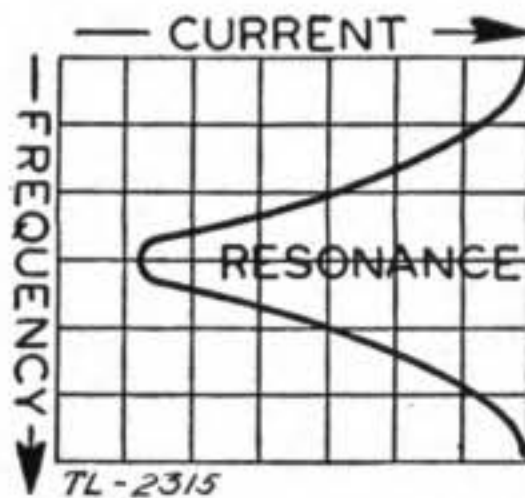


Figure 31. Current flow in parallel-resonant circuit.

the current will rapidly decrease from its highest value at the low frequency to a minimum at the resonant frequency, and will then rise again to a high value at the high frequency, as shown by the graph of figure 31.

d. The line current is the difference between the currents flowing through the inductive and capacitive branches of the circuit, as

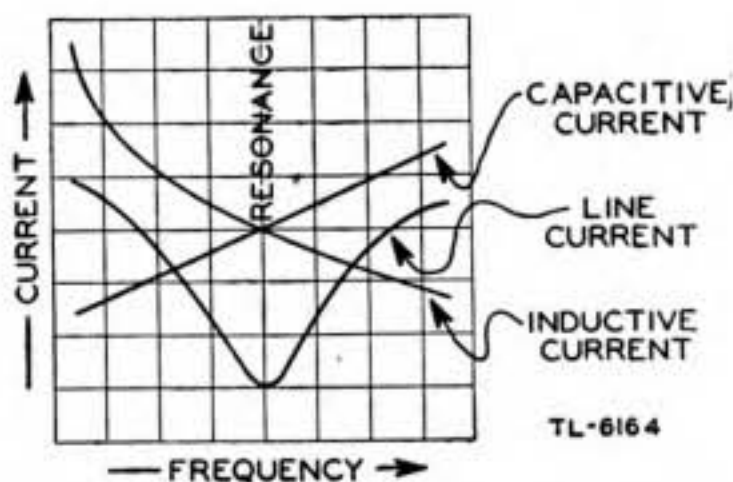


Figure 32. Flow of currents through branches of parallel-resonant circuit.

shown by the graph of figure 32. Because of the presence of some resistance, the two branch currents can never cancel each other completely. The lower the resistance, the lower is the line current. Although

the line current may be very small, the current circulating between the coil and the capacitor may be very large.

e. Since the total current, or line current, in a parallel-resonant circuit is minimum at the resonant frequency, the impedance of the circuit (or the total opposition to current flow) must be at a maximum at resonance and decrease on either side of the resonant frequency, as shown by the graph in figure 33.

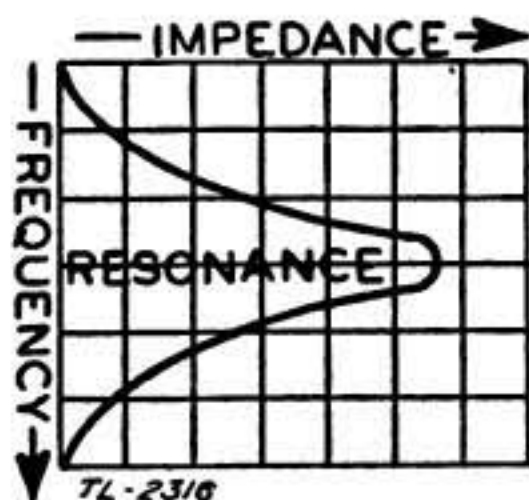


Figure 33. Impedance curve of parallel-resonant circuit.

f. The selectivity of a parallel-tuned circuit is inversely related to the resistance in either branch of the circuit; that is, increased resistance in either branch of the parallel circuit acts to decrease the selectivity.

g. For a fixed frequency of the a-c generator in a circuit such as is shown in figure 30, a variation of the capacitor C is accompanied by a variation of the ammeter (line current) reading as the impedance of the circuit changes. Minimum current in the line indicates that there is a maximum circulating current within the parallel-tuned circuit. A parallel-resonant circuit in a radio transmitter is tuned in this manner, by watching for a dip in the ammeter reading.

h. The impedance of parallel-tuned circuits is very high at the resonant frequency and low at all other frequencies. For this reason, they are used with vacuum tubes to generate, detect, or amplify signals of a given frequency. Vacuum tubes are comparatively high-impedance devices, and for proper operation must be connected to high-impedance circuits, such as parallel-tuned circuits. Parallel-resonant circuits are also used as filters (par. 26). A third important use of the parallel-tuned circuit is in the principle of the tank circuit employed in radio transmitters.

25. Tank Circuit Principle

a. If the capacitor in a parallel-tuned circuit is charged by means of a battery (direct current) and the battery is then disconnected, an alternating current of very short duration will be generated at the resonant frequency of the circuit.

b. This current is produced in the following manner:

(1) The capacitor will discharge into the inductor, causing current to flow through it. This current flow builds up a magnetic field around the inductor.

(2) As the capacitor becomes discharged, the current flow stops and the field collapses.

(3) A voltage, of such polarity that it causes the current to continue to flow in the same direction, is induced in the coil by the collapse of the field.

(4) This current flowing into the capacitor charges it with a voltage of opposite polarity to the original charge from the battery. The capacitor now discharges in the opposite direction through the inductor, and the process is repeated.

(5) To summarize, then, the energy in the circuit which originally came from the battery is first stored in the capacitor as a charge and then is transferred to the magnetic field around the inductor by the current flowing in the circuit. This current is alternating, since it reverses its direction at the resonant frequency of the tuned circuit.

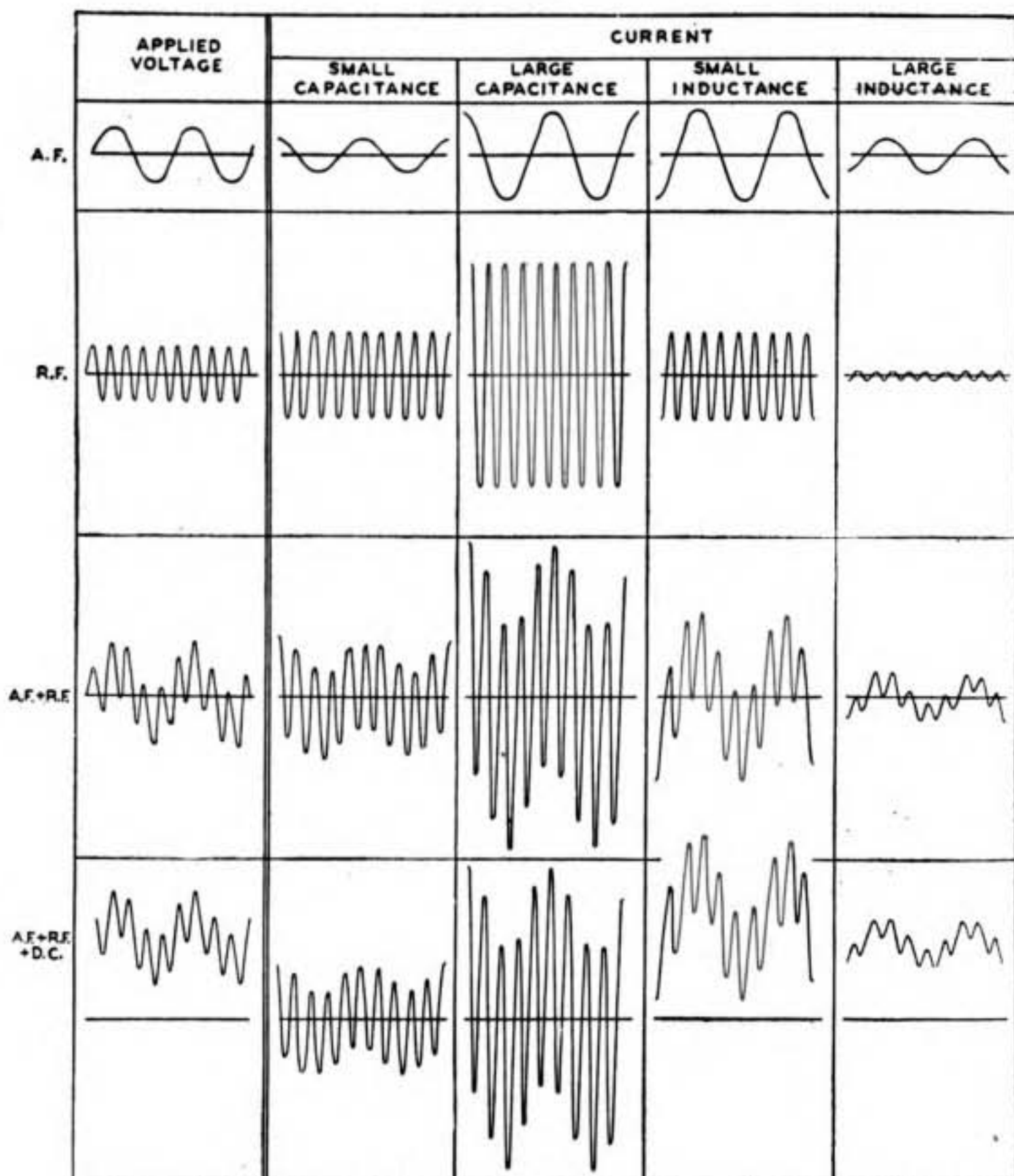
c. This process would repeat itself indefinitely if the circuit contained *no* resistance. But since all circuits contain at least some resistance, the process will continue only until the energy which has been applied to the circuit has been dissipated, or used up, by the circuit resistance.

d. In order to produce a sustained alternating current, it is only necessary to supply sufficient power to such a parallel-tuned circuit to overcome the losses due to its resistance. It is possible to do this in certain vacuum tube circuits used in transmitters as will be explained later. Alternating currents generated in such parallel-tuned tank circuits are called *oscillatory currents*. It is because such a parallel-tuned circuit can store power for a time that it is called a *tank circuit*.

26. Filters

a. Filters are necessary for selecting energy at certain desired frequencies and for rejecting energy at undesired frequencies. Individual capacitors and inductors have properties in a circuit which make them suitable either singly or in combination with each other, for use as wide-frequency-range filters; low-pass filters and high-pass filters are two examples of this type. Resonant-tuned circuits are also employed as filters for the passage or rejection of specific frequencies; band-pass filters and band-rejection filters are examples of this type.

b. Individual capacitors and inductors have a characteristic frequency range discrimination. Inductors tend to pass low a-c frequencies and retard high frequencies; capacitors tend to pass high a-c frequencies and retard low frequencies. This retarding effect is known as *attenuation*. Figure 34 presents a pictorial concept of currents which flow in series



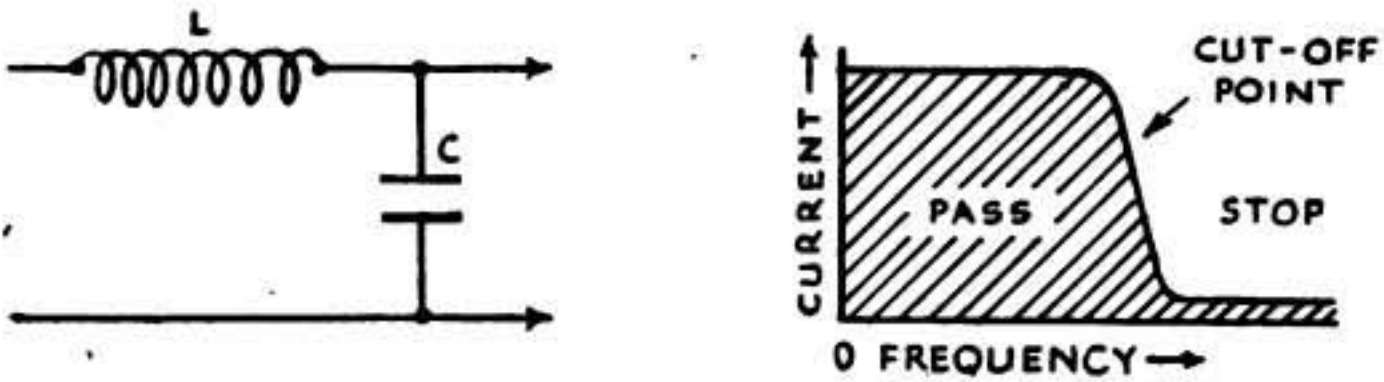
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Figure 34. Filter action of individual series capacitors and inductors.

circuits corresponding to various applied potentials. The characteristic frequency discrimination of large and small capacitors and of large and small inductors is shown for four different types of input signals: a-f, r-f, a-f and r-f, and a-f and r-f with d-c component. The attenuation of certain of these input frequencies should be noted. Resistances do not provide any filtering action in themselves, for they impede all currents which pass through them, regardless of frequency. The less the resistance in a filter circuit, however, the sharper will be the dividing line between the frequencies which pass and those which are blocked or attenuated.

c. A *low-pass filter* is designed to pass all frequencies below a predetermined critical frequency, or cut-off frequency, and substantially

reduce, or attenuate, currents of all frequencies above this cut-off frequency. Such a filter is shown in figure 35 with a graph of a typical cut-off characteristic. The low-pass filter will also pass direct

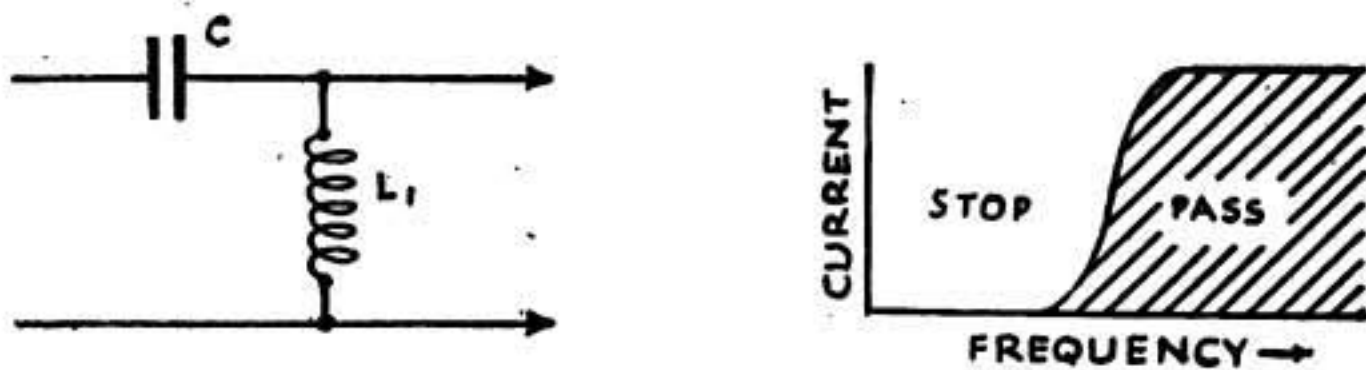


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Figure 35. Low-pass filter and its frequency-current characteristic.

current and extremely low alternating current without opposition, and is therefore widely used to filter, or smooth, the output of radio power supplies. This smoothing action is explained more fully in paragraph 35c.

d. A *high-pass filter* is designed to pass currents of all frequencies above the predetermined cut-off frequency, and retard, or attenuate, the currents of all frequencies below this cut-off frequency. The



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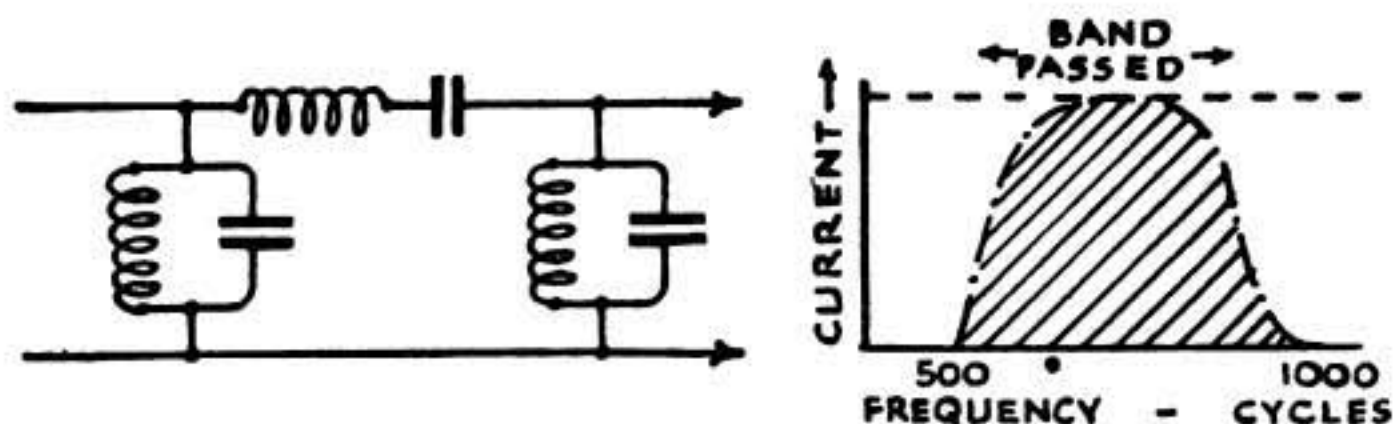
Figure 36. High-pass filter and its frequency-current characteristic.

inductor and capacitor of the low-pass filter have merely been interchanged to make the high-pass filter (fig. 36). Since all frequencies below the cut-off frequency are greatly attenuated a filter of this type will stop the flow of direct current in most cases.

e. Resonant (tuned) circuits have certain characteristics which make them ideal for a certain type of filter, where high selectivity is desired. A series-resonant circuit offers a low impedance to currents of the particular frequency to which it is tuned, and a relatively high impedance to currents of all other frequencies. A parallel-resonant circuit, on the other hand, offers a very high impedance to currents of its natural, or resonant, frequency, and a relatively low impedance to others.

f. A *band-pass filter* is designed to pass currents of frequencies within a continuous band, limited by an upper and lower cut-off

frequency, and substantially to reduce, or attenuate, all frequencies above and below that band. A typical band-pass filter is shown in figure 37, with a graph illustrating the band of frequencies which it will pass. The series- and parallel-resonant circuits are all tuned to the frequency band desired. The parallel-tuned circuits offer a high impedance to the frequencies within this band, while the series-tuned circuit offers very little impedance. Thus, these desired frequencies

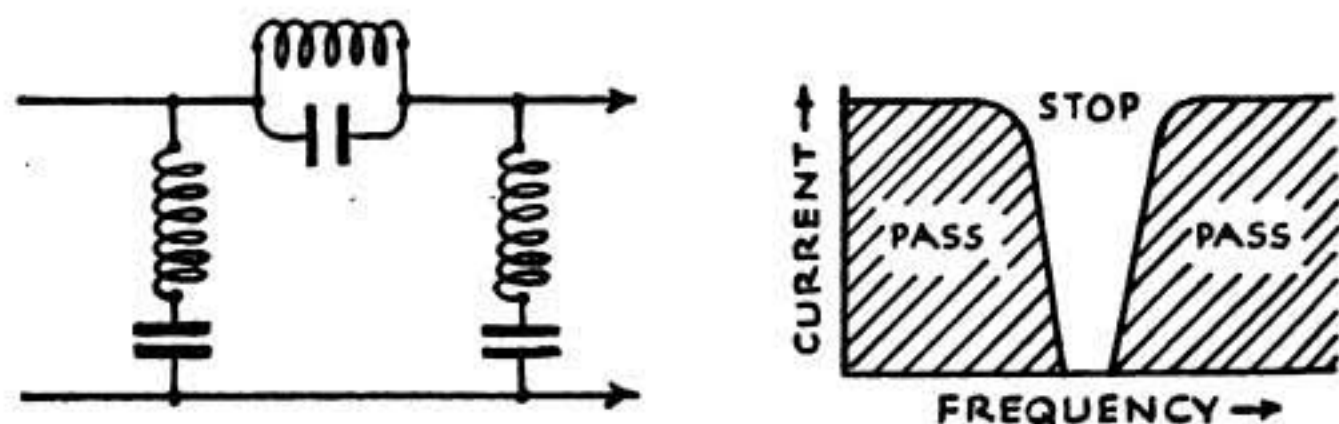


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Figure 37. Band-pass filter and its frequency-current characteristic.

within the band will travel on to the rest of the circuit without being affected; but the currents of unwanted frequencies, that is, frequencies outside the band, will meet with a high impedance and be stopped. Band-pass filters are used in the tuned circuits of tuned r-f receivers. They are also used in certain sections of a superheterodyne radio receiver.

g. A *band-elimination filter*, or *band-rejection filter*, is designed to suppress currents of all frequencies within a continuous band, limited by an upper and lower cut-off frequency and to pass all frequencies above and below that band. Such a band-rejection filter is shown in figure 38, with a graph of its frequency characteristic. This type of filter is just the opposite of the band-pass filter; currents of frequencies



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Figure 38. Band-rejection filter and its frequency-current characteristic.

within the band are opposed, or stopped. The two series-tuned circuits and the parallel-resonant circuit are all tuned to the frequency band desired. The parallel-tuned circuit offers a high impedance to this band of frequencies only, and the series-tuned circuits offer very little imped-

ance; therefore, the signals within the frequency band are stopped. All other frequencies, that is, all frequencies outside the band, pass through the parallel circuit which offers little impedance.

h. A *wave trap*, sometimes used in the antenna circuits of radio receivers, is a form of band-elimination filter. There are two types of these wave traps: the parallel-tuned filter and the series-tuned

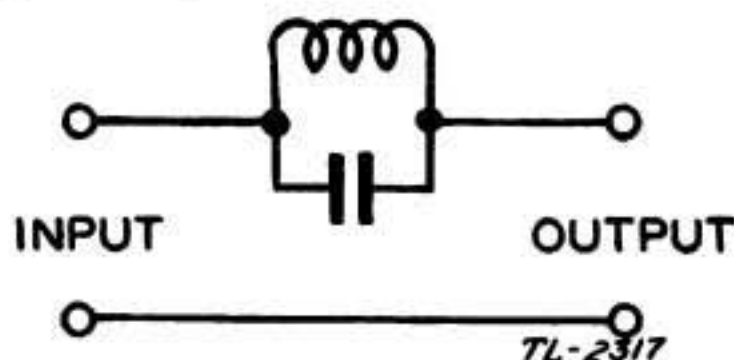


Figure 39. Parallel-tuned wave trap.

filter. A parallel-resonant circuit, connected as shown in figure 39, is tuned to resonance at the frequency of the undesired signal; the wave trap then presents a high impedance to currents of this unwanted frequency, and allows currents of all other frequencies to enter the receiver. A series-resonant circuit, connected as shown in figure 40,

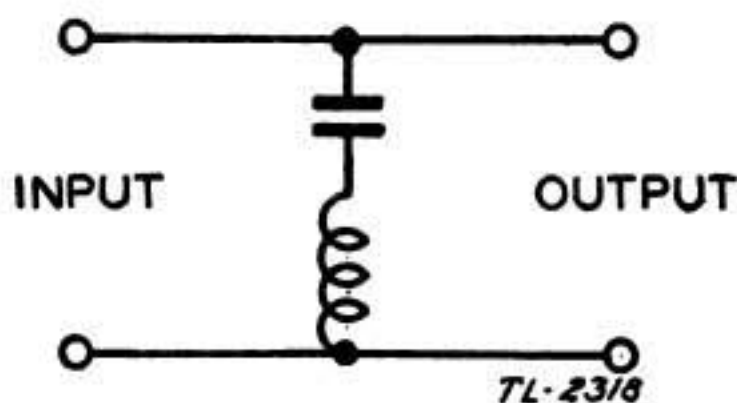


Figure 40. Series-tuned wave trap.

can be tuned to resonance at the frequency of the undesired signal, and these unwanted currents will be effectively bypassed, generally to ground, without affecting currents of all other frequencies.

27. Coupled Circuits: Transformer

a. Since every radio receiver and transmitter is composed of a number of circuits, or stages, methods must be devised for connecting, or coupling the output of each stage to the input of the next circuit. One of the most widely used methods for transferring power from one stage to another is the *transformer*. Two important properties of the transformer are *the turns and voltage ratio* and *the turns and impedance ratio*. (See TM 1-455.)

b. *The voltage ratio of a transformer is proportional to its turns ratio.* In other words, if a transformer has twice as many turns of wire on its secondary as on its primary side, the secondary voltage will be twice the primary voltage. Conversely, if a transformer has

only half as many turns on its secondary winding as on its primary winding, the secondary voltage will be half the primary voltage. Thus, by using a transformer, it is possible either to step up or step down the a-c voltage appearing in a circuit. This property is widely used in radio circuits where it is necessary to step up the signal voltage from one stage to the next. By using a step-up transformer it is possible to obtain an actual voltage gain, or voltage amplification.

c. *The impedance ratio of a transformer is equal to the square of the turns ratio.* Thus if a transformer has a turns ratio of 3 to 1 (or three times as many turns on one winding as on the other), its impedance ratio will be 9 to 1, and the winding having three times as many turns will have nine times the impedance of the other winding. By choosing a transformer with the proper turns ratio, it is therefore possible to match the impedances of two circuits. Among the requirements placed on any system for transferring power from one circuit to another, impedance matching is one of the most important, since it is an electrical rule that *in order to transfer the maximum power from one circuit to another, the impedances of the two circuits must be equal.*

d. For a practical example of impedance matching with a transformer, assume that a loudspeaker with an input impedance of 500 ohms is to be connected to an a-f amplifier stage with an output impedance of 8,000 ohms. In order to transfer the maximum a-f power from the a-f amplifier to the loudspeaker, the output impedance of the amplifier must match the input impedance of the speaker. By applying the impedance-turns ratio rule, the impedance ratio of the amplifier to the speaker will be:

$$\frac{8,000}{500} = \frac{16}{1}$$

e. Since the impedance ratio of a transformer equals the square of the turns ratio, *the turns ratio equals the square root of the impedance ratio.* In the above problem, the impedance ratio is 16 to 1, and since the square root of 16 equals 4, the transformer must have a turns ratio of 4 to 1 in order to match the amplifier to the speaker.

28. Coupled Circuits: r-f Transformers

a. The properties of the transformer just discussed hold true for all types including r-f transformers, provided that all of the magnetic lines of force which cut the primary coil also cut the secondary. However, r-f transformers serve two purposes at the same time: they are used to couple the output of one stage to that of another stage, and, together with variable capacitors, they form the tuned circuits of radio sets. If an r-f transformer has *one* of its windings tuned by a variable capacitor in a circuit, it is called a *single-tuned transformer*; if *both*

of the windings are tuned by capacitors, it is known as a *double-tuned transformer*.

b. Single-tuned transformers are used in the majority of r-f amplifier circuits in radio receivers. Such transformers usually have untuned primary coils and tuned secondaries. The number of turns on the secondary will depend on the frequency range to be covered by the tuned circuit; but the number of turns on the primary will depend on the desired voltage step-up in the transformer, and the output impedance of the circuit in which it is to be connected. The transference of energy from the primary to the secondary of a transformer is due to the field of one coil passing through the windings of the other. In the untuned transformer, the power transferred from one winding to

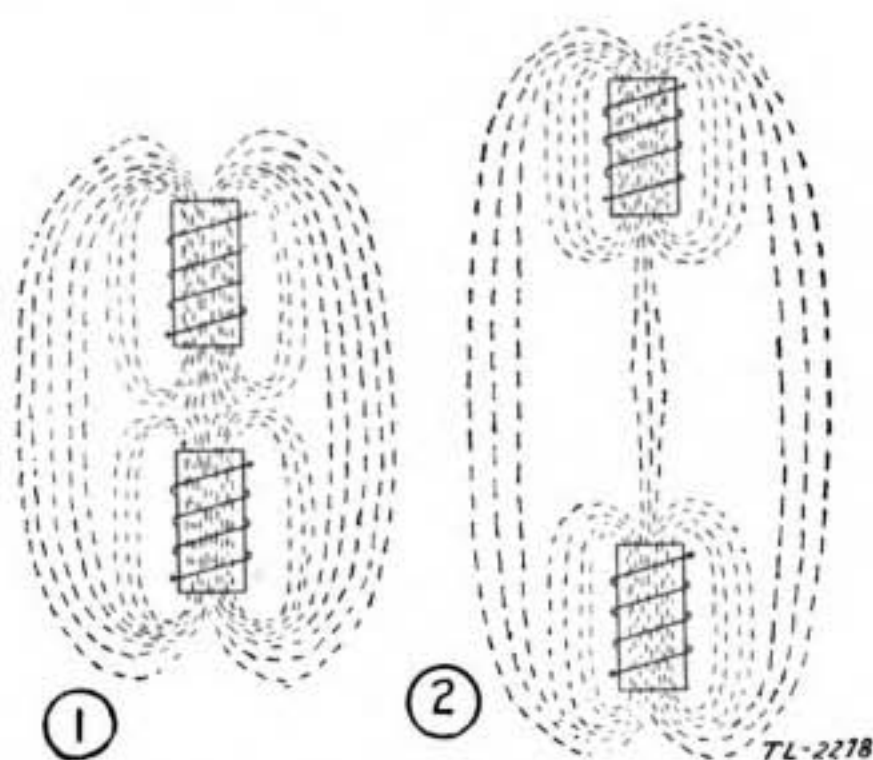


Figure 41. Coupled coils.

the other will depend on how close one coil is placed to the other, and consequently how many lines of force of the field of one coil pass through the windings of the other. (See fig. 41.) If the two coils are placed close together, they are closely coupled; if the coils are placed some distance apart, they are loosely coupled. From this discussion it would seem desirable to couple the windings of an r-f transformer as closely as possible, in order to obtain the greatest possible power transfer. However, in the case of the tuned transformer, there is greater concern about the selectivity of the tuned circuit (formed by the tuned secondary winding of the transformer) than there is about the maximum power transfer. In other words, a reasonable power transfer is wanted at the resonant frequency, and minimum power transfer at all other frequencies. If the coils of the single-tuned r-f transformer are coupled too closely, the power transfer over all frequencies may be at a maximum, but the ratio between the power transferred at the desired frequency and the power transferred at the undesired frequencies will be low, and consequently the selectivity will

be poor. On the other hand, if the coils are coupled too loosely, the power transfer even at the resonant frequency will be unsatisfactory, although the resulting selectivity may be excellent. Between these two extremes there is a certain degree of coupling which will give both satisfactory selectivity and good power transfer at the resonant fre-

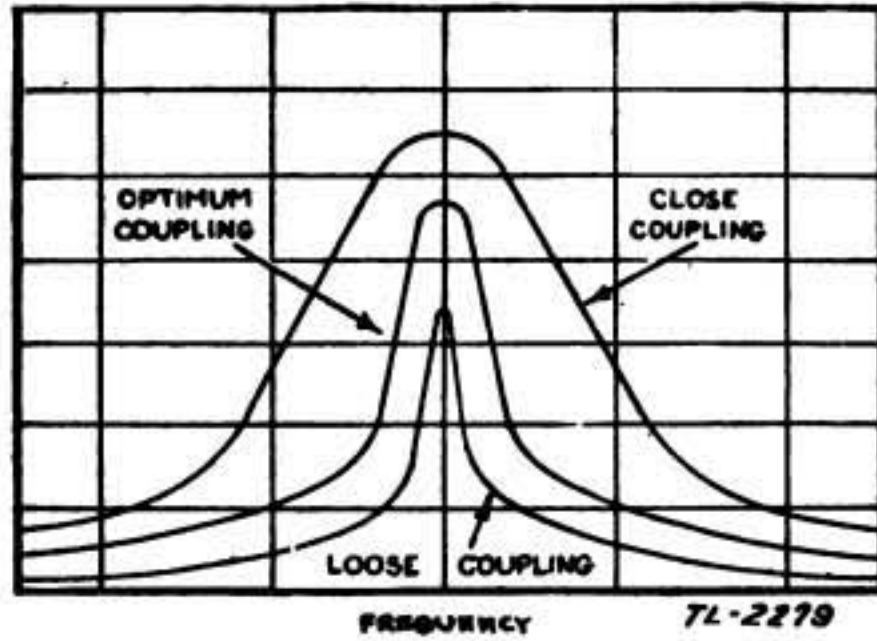


Figure 42. Selectivity curves of a typical single-tuned r-f transformer, showing variations in transfer of power with changes of frequency.

quency. This degree of coupling is known as *optimum coupling*. Figure 42 shows the selectivity curves of a typical single-tuned r-f transformer for three different degrees of coupling between its primary and secondary coils.

c. *Double-tuned transformers* have both primary and secondary windings tuned by capacitors, and are widely used in the intermediate-frequency amplifier stages of superheterodyne receivers. The double-tuned transformers used in such circuits are called *i-f transformers* (fig. 15④), and must be carefully tuned to allow the passage of a very narrow band of radio frequency known as the *intermediate frequency* of superheterodyne receiver. The effect of the degree of coupling on

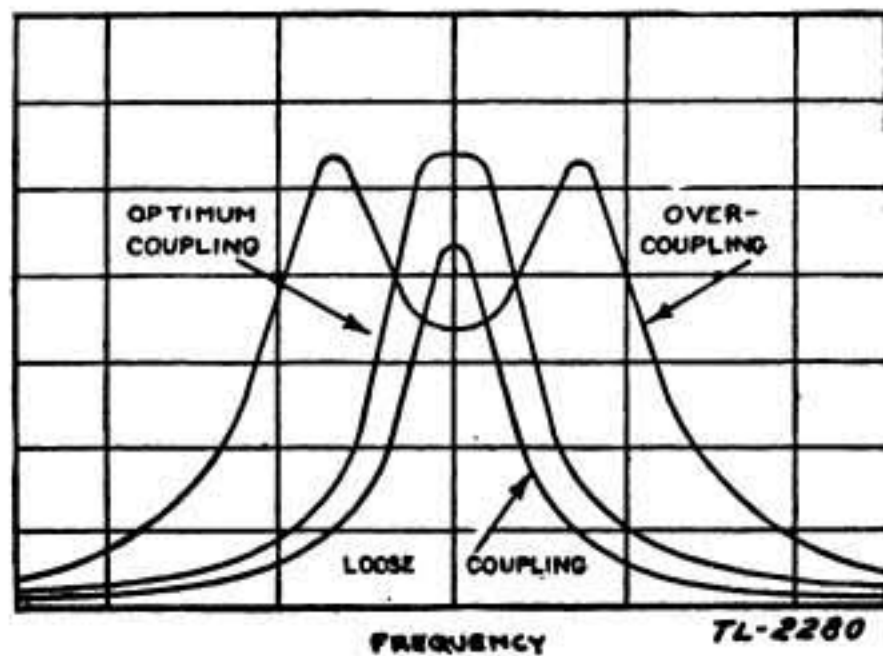


Figure 43. Selectivity curves of a typical double-tuned r-f transformer, showing variations in transfer of power with changes in frequency.

the selectivity of double-tuned transformers is more pronounced than in the case of the single-tuned transformer, since two circuits, both tuned to the same frequency, are coupled together. The double-tuned transformer has greater selectivity than the single-tuned r-f transformer. The selectivity curve will be more sharply peaked and will have steeper sides, indicating better rejection of signals on either side of the resonant frequency. Figure 43 shows the selectivity curves of a double-tuned transformer for three different degrees of coupling. Compare these curves with those for the single-tuned transformer shown in figure 42; note the flat top on the curve for optimum coupling, indicating that a band of frequencies on either side of the resonant frequency will be passed by a double-tuned transformer with the proper degree of coupling. This band-pass effect is very important in the reception of radiotelephone signals, as will be seen later. Since double-tuned transformers will pass a narrow band of frequencies while rejecting all other frequencies, they are sometimes called *band-pass filters*. Note the double hump on the curve for overcoupling, indicating that a double-tuned transformer will have two resonant frequencies equidistant from the proper resonant frequency if the coupling is increased past the optimum point.

d. The importance of maintaining the proper coupling between the coils of an r-f transformer cannot be overstressed. Overcoupling will reduce the selectivity of a set; loose coupling will reduce the sensitivity of the set.

29. Coupled Circuits: Resistance Coupling

a. Resistors are often used to couple the output of one circuit to the input of another, particularly in a-f amplifiers. Resistance coupling may be used to step down the voltage from one stage to another. (See

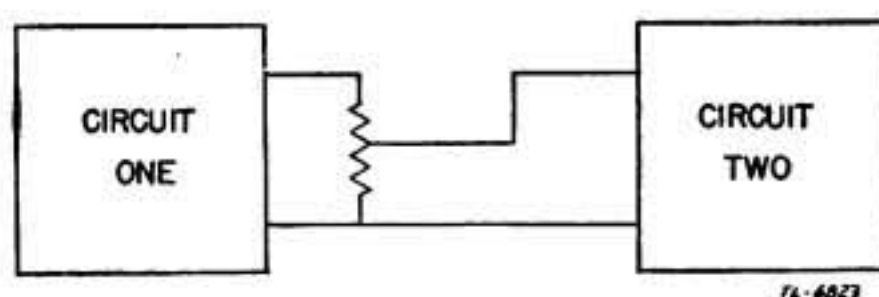


Figure 44. Resistance coupling used to step down voltage.

fig. 44.) In this arrangement, if the tap on the resistor is placed halfway between the ends of the resistor, the voltage applied to circuit two will be half the output voltage of circuit one. Other step-down voltage ratios may be obtained by moving the tap up or down the resistor.

b. To resistance-couple two stages, and pass only alternating current from one to the other, as is the case in most radio circuits, a blocking capacitor is used (fig. 45). This form of resistance coupling, sometimes

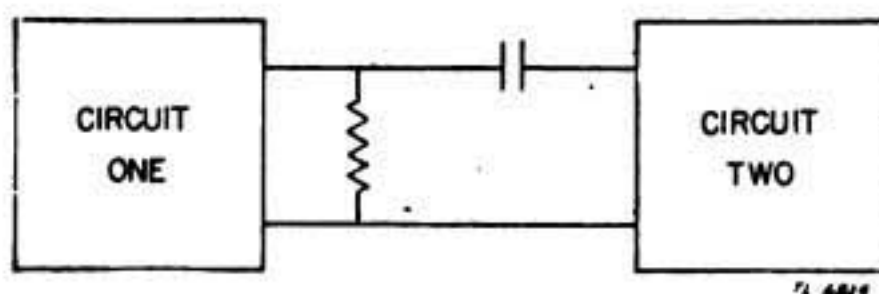


Figure 45. Resistance coupling with blocking capacitor.

known as *resistance-capacitance coupling*, has a wide use in the a-f amplifiers of radio receivers.

30. Coupled Circuits: Inductance Coupling

a. Inductance coupling is used mainly to couple the r-f amplifier circuits of radio transmitters, although it finds some application in the a-f circuits of receivers. Inductance coupling may be used to step down the voltage from one circuit to another in exactly the same way that resistance coupling is used in figure 44, except that a tapped inductor is substituted for the resistor shown. The step-down voltage ratio will be equal to *the turns ratio of the total winding to the tapped portion*. That is, if the section of the winding applied to circuit two has only one-third of the turns of the total winding, the voltage appearing across this portion of the winding will be one-third of the voltage across the whole coil,

b. In like manner, inductance coupling may be used to step up the voltage from one circuit to another (fig. 46). The step-up voltage ratio also will be equal to the turns ratio of the total winding to the tapped

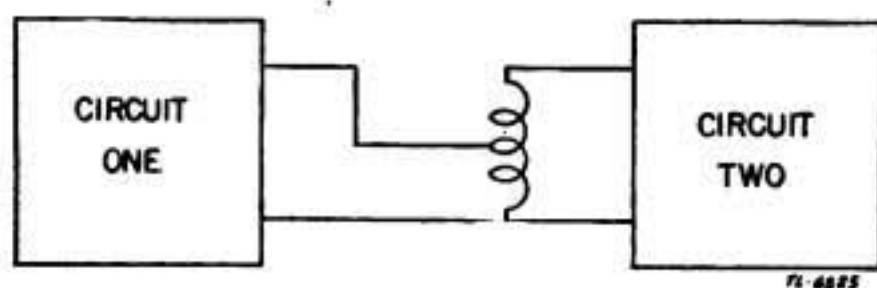


Figure 46. Inductance coupling used to step up voltage.

portion. Thus, if circuit one is connected across one-third of the turns of the coil, the voltage appearing in circuit two will be three times as great as the voltage output of circuit one. Since the tapped inductor operates in much the same fashion as does the transformer, the tapped inductor is often called an *autotransformer*.

c. Impedance matching can be accomplished with tapped inductors, in much the same way as with transformers. The rule is as follows: The impedance *ratio* of the whole coil to the tapped section equals *the square of the turns ration of the whole coil to the tapped section*.

d. In inductance coupling, as in resistance coupling, to prevent the flow of direct current from one circuit to the other, while allowing

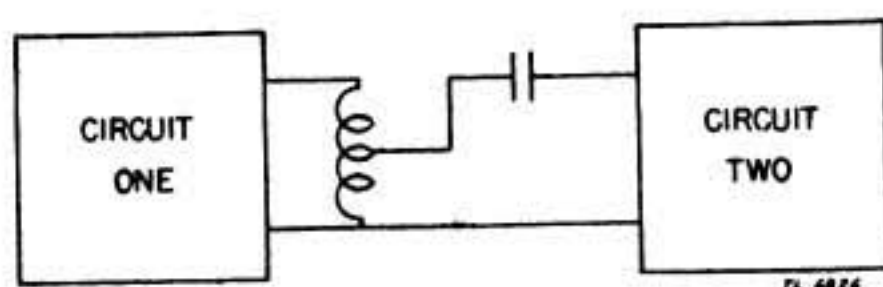


Figure 47. Impedance-capacitance coupling used to step down voltage.

the a-c signal to pass, a *blocking capacitor* is employed. This method of coupling is shown in figure 47, and is often called *impedance-capacitance coupling*.

31. Distributed Inductance and Capacitance

a. In addition to the inductance and capacitance included in inductors and capacitors, there are distributed, or stray, inductance and capacitance effects present in miscellaneous components of radio instruments, as in connecting wires, switches, and sockets. These become of considerable concern at radio frequencies.

b. *Capacitive reactance* is inversely proportional to the frequency ($X_c = \frac{1}{2\pi f C}$). This means that as the frequency of an applied voltage is increased, the capacitance of the circuit offers less opposition to the flow of current. At high frequencies undesirably large currents may appear where negligible currents would flow at low frequencies. The capacitance which occurs between elements of a vacuum tube and between adjacent turns of a coil present a large capacitive reactance at the lower frequencies. However, at radio frequencies, the reactance may be reduced to such a point that the increased magnitude of the current flowing across it determines the upper frequency limit for the usefulness of the associated circuit.

c. *Inductive reactance* increases in direct proportion to frequency ($X_L = 2\pi f L$), or, as the frequency of an applied voltage is increased, the inductance of the circuit offers more opposition to the flow of current. A simple connecting wire, the inductive reactance of which may be insignificant at low frequencies, may have a sufficiently large inductive reactance at higher frequencies to render an instrument inoperative.

32. Effective a-c Resistance

Fundamentally, a measure of the resistance of a circuit is given by the power dissipated as heat, when unit current is flowing in the circuit. In its broadest sense, the term "resistance" is taken to mean all effects

leading to dissipation of energy in such form that the energy is not recoverable for any useful purpose within the immediate system. Thus a radio antenna for transmitting is said to have a radiation resistance associated with radiative losses, that is, with the energy which is radiated into space; and a particular transmitter or receiver circuit may be said to exhibit certain reflected resistance because of the power consumed by other circuits which it directly or indirectly supplies. With alternating current, for a given current magnitude, considerably more electrical power may be consumed than is required by the same circuit with direct current. The resistance which is indicated by a-c power consumption is called *effective a-c resistance*. Part of this additional power is required to maintain the heat losses accompanying parasitic circulating currents (eddy currents) which are induced in conductors of the circuit (in particular, in transformer cores) by the varying magnetic field. Another source of a-c electrical power dissipation is represented by dielectric and other losses. A further factor which makes for more required power for a given magnitude of alternating current is the skin effect: the tendency of alternating currents to travel with greater density near the surface of the conductor than at the center. This tendency increases with frequency. The magnetic field about a current-carrying conductor is more intense at the center of the conductor than it is near the surface of the conductor. Thus the back voltage set up by the rising and falling magnetic field is greater at the center than near the surface, and practically all of the current through a wire at high frequencies is confined to the outer surface of the conductor. The result is increased heating for the same current, that is, higher resistance. The nonuniform distribution of current throughout the cross section of a conductor at high frequencies is more pronounced if the conductor is wound into the form of a coil than it is if it is used as a straight wire. At radio frequencies, the effective a-c resistance of a coil may be 10 or 100 times its true d-c resistance. Wherever alternating currents are studied, it is generally understood, if not specifically stated, that resistance means *effective a-c resistance*.

SECTION IV

VACUUM TUBES

33. Electron

a. The whole foundation of electricity is based upon the *electron*, a minute negatively charged particle. Atoms, of which all matter is composed, consist of a positively charged nucleus around which are grouped a number of electrons. The physical properties of any material depend upon the number of electrons and the size of the nucleus. In all matter there are a certain number of free electrons. The movement of these free electrons is known as a current of electricity. If the movement of electrons is in one direction only, the current is direct. If, however, the source of voltage is alternated between positive and negative, the flow of electrons will likewise alternate; this is known as alternating current.

b. If certain metals, or metallic substances such as metallic *oxides*, are heated to a high temperature either by means of a flame or by passing current through them, they have the property of throwing off, or emitting, electrons. The element in a vacuum tube which is heated to emit electrons is called the *cathode*.

c. If the cathode is heated to a high temperature in the open air, it will burn up because of the presence of oxygen in the air. For this reason the cathode is placed in a glass or metal bulb from which all air has been removed. Such a space is known as a *vacuum*. Since it is difficult to heat an element in a vacuum tube by means of fire or flame, the cathode, which is in the form of a filament, is directly heated by passing a current through it.

d. Any isolated *positively charged* body in the vicinity of the electron emitter will attract the *negatively charged* electrons. The positive charge on the body will soon be canceled by the electrons attracted to it unless some means is employed to remove the electrons as fast as they arrive. This can be done by connecting a source of constant voltage between the positively charged body and the electron emitter (fig. 48). This is the general arrangement in a two-element tube, or *diode*. It is also the basis of operation of all types of vacuum tubes.

e. The emitter, or cathode, of a vacuum tube may resemble the familiar incandescent lamp filament which is heated by passing a current through it. The positively charged body usually surrounds the

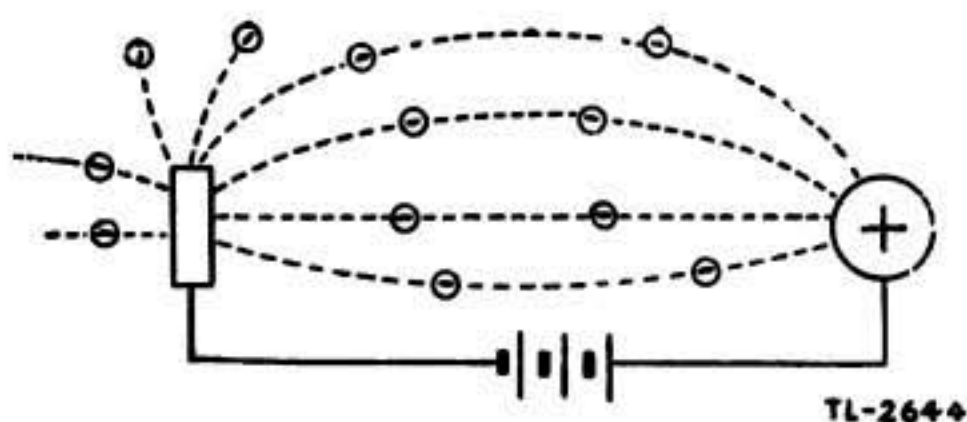


Figure 48. Emitted electrons attracted by a positively charged body.

emitter and is called the *plate*, or *anode*. It should be noted that electrons travel from negative to positive.

f. Two types of cathodes, or emitters, are used in radio tubes. In one, known as the *filament* or *directly heated* type, the heating current is passed through the cathode itself. In the other, known as the *indirectly heated* type, the current is passed through a heating element, which in turn heats the cathode to a temperature sufficiently high for electron emission. In the indirectly heated type, the cathode is an oxide-coated metal sleeve which is placed over the heater element.

g. The higher the temperature of the cathode, the more electrons it will emit. However, if too much voltage is applied to a cathode, the heavy current flow will cause the filament or heater to burn out. The safe filament or heater voltage is determined by the manufacturer, and this voltage rating must be observed for satisfactory operation. The cathode of a tube will not continue to emit electrons indefinitely. After several thousand hours of operation, the number of electrons emitted will gradually decrease, until finally an insufficient number is emitted for proper operation. The decrease in emission capacity is due to the chemical change which takes place in the cathode. This is one of the reasons why tubes wear out.

34. Operation of Diode

a. The *diode* is the simplest type of vacuum tube, and consists of only two elements: a cathode and a plate. The operation of the diode depends on the fact that if a positive voltage is applied to the plate with respect to the heated cathode, *current will flow through the tube*; if a negative voltage is applied to the plate with respect to the cathode, *current will not flow through the tube*.

b. When the positive terminal of a battery is connected to the plate of a diode and the negative terminal is connected to the cathode, the plate will be positive with respect to the cathode. Since the electrons emitted by the cathode are negative particles of electricity, and there is a positive charge on the plate, the electrons emitted by the cathode will be drawn to the plate (fig. 49). In other words, there is an electron flow through the tube, which results in a current flow in the circuit. If

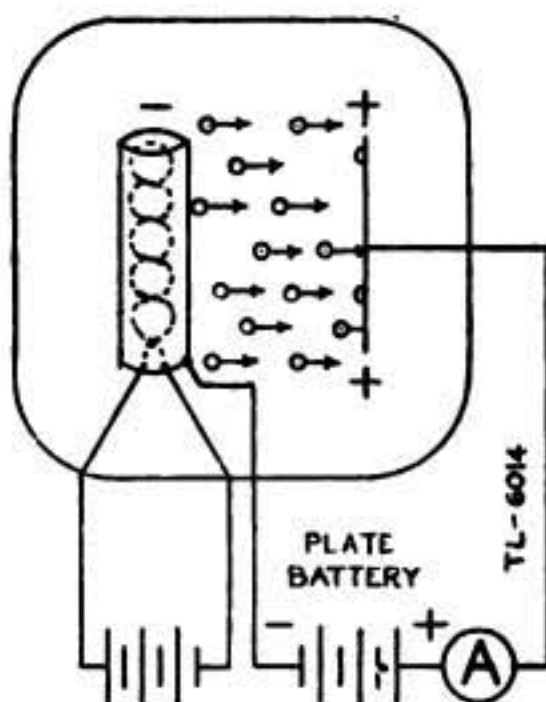


Figure 49. Electron flow in a diode when plate is positive.

the flow of current in the circuit is measured by meter *A* (fig. 49) while the voltage applied to the plate (known as *battery voltage* or *plate voltage*) is increased, it will be seen that the current flow through the tube, known as the *plate current*, increases. This is illustrated by the plate-voltage plate-current curve of figure 50.

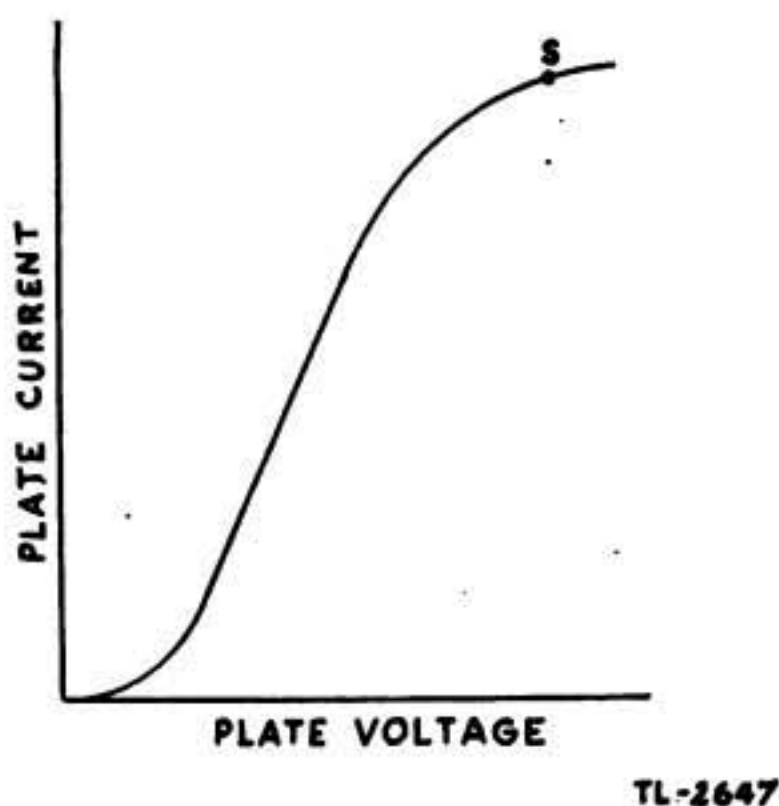


Figure 50. Plate current flow in a diode.

c. When the negative terminal of a battery is connected to the plate of the diode and the positive terminal is connected to the cathode (fig. 51), the plate will be negative with respect to the cathode, and therefore no electrons will be attracted to the plate. Since no electrons are traveling across to the plate, no current will flow through the tube.

d. The diode is a *conductor* when the plate voltage is positive, and is a *nonconductor* when the plate voltage is negative. This property of the diode permits the use of this tube for two very useful functions: *rectification* and *detection*.

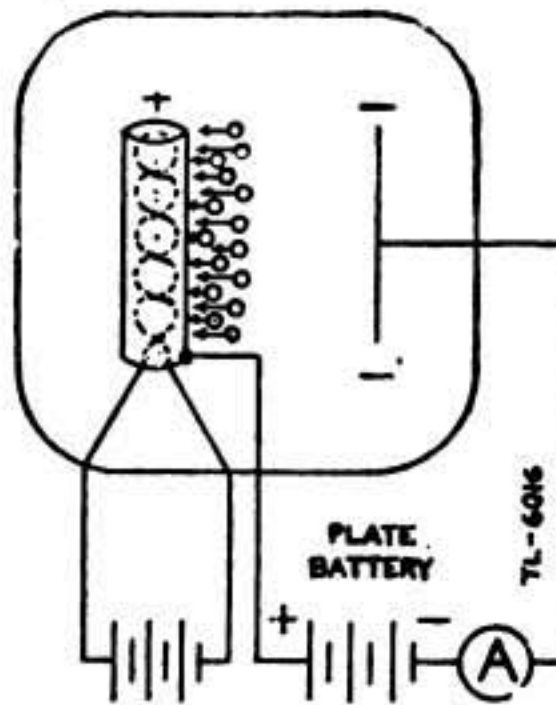


Figure 51. Diode action when plate is negative.

35. Diode as Rectifier

a. The ability of a diode to conduct, or pass, current in only one direction makes possible its use as a rectifier to convert alternating current into direct current. A diagram of a simple diode rectifier circuit is shown in figure 52. If an a-c source is connected between the plate and the cathode of such a circuit, one half of each a-c cycle will be positive and the other half will be negative. Therefore, the plate of the diode will be made alternately positive and negative with respect to the cathode. Since the diode conducts only when the plate is positive,

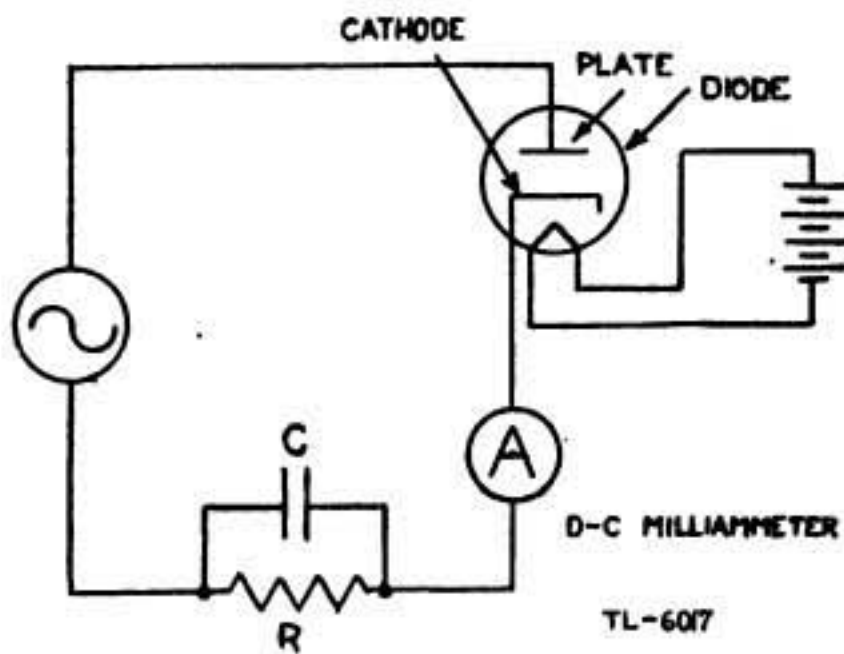


Figure 52. Diode used as a half-wave rectifier.

current flows through the tube only on the positive half-cycles of the a-c voltage, as shown in figure 53. Since the current through the diode flows in one direction only, it is direct current. This type of diode rectifier circuit is called a *half-wave rectifier*, since it rectifies only during one-half of the a-c cycle.

b. It can be seen from figure 53 that this direct current is quite different from pure direct current, since it rises from zero to a maximum and returns to zero during the positive half-cycle of the alternating current, and does not flow at all during the negative half-cycle. To

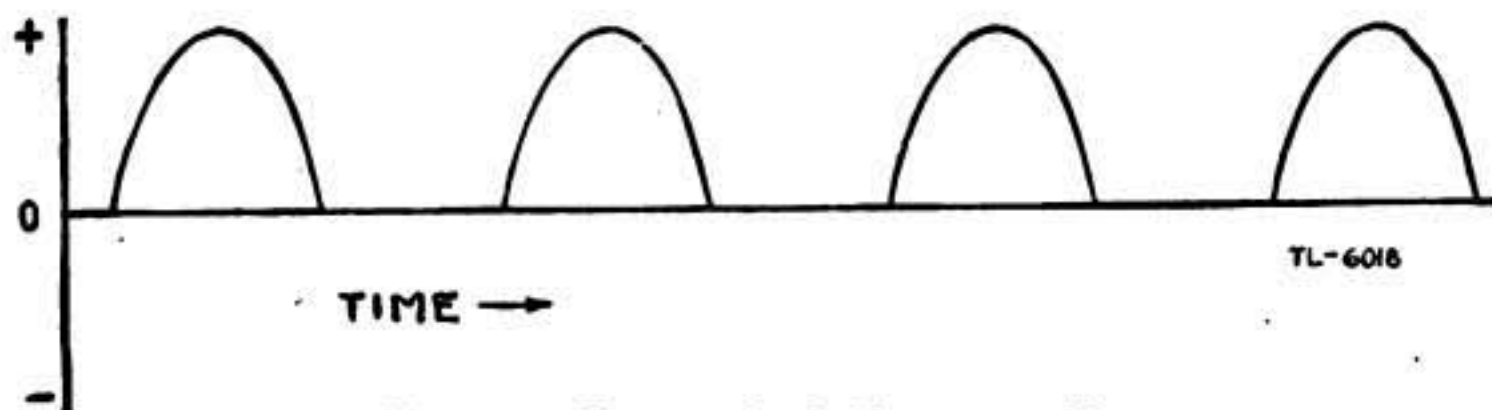
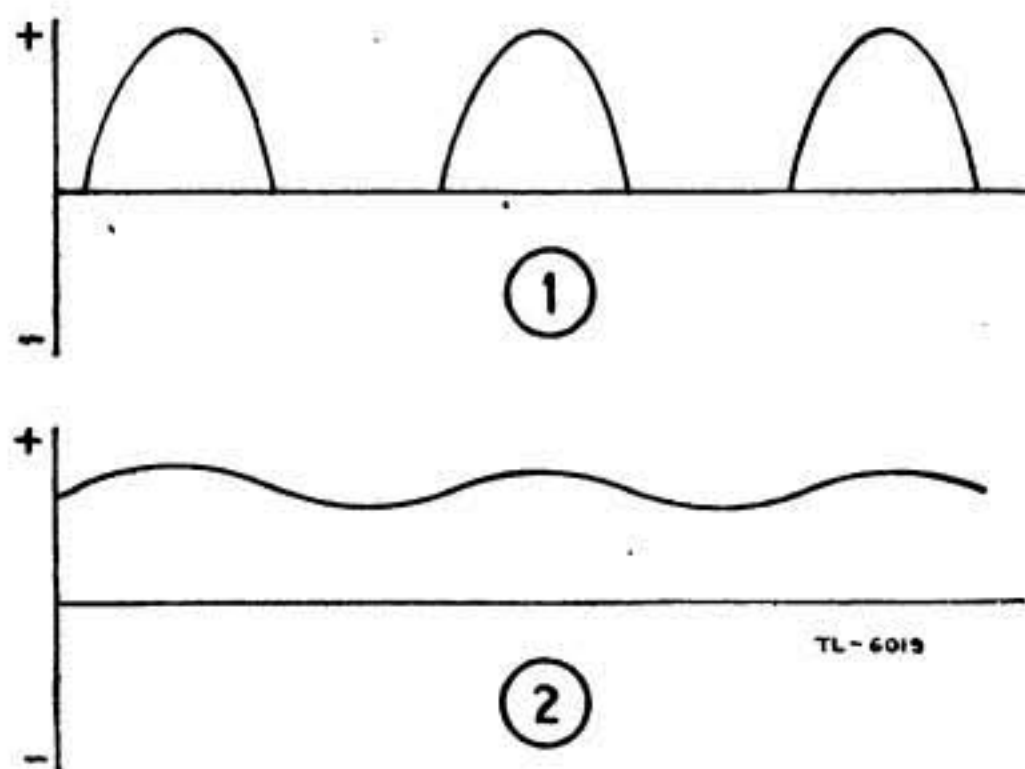


Figure 53. Output of a half-wave rectifier.

distinguish this type of current from pure direct current, it is referred to as *pulsating direct current*, or *rectified alternating current*.

c. To convert this rectified alternating current into pure direct current, the fluctuations must be removed. In other words, it is necessary to cut off the humps at the tops of the half-cycles of current flow, and to fill in the gaps due to the half-cycles of no current flow. This process is called *filtering*. In the circuit of figure 52, the d-c voltage output will appear across the load resistor R , because of the current flowing through it during the positive half-cycles. The capacitor C , having a small reactance at the a-c frequency, is connected across this resistor. This capacitor will become charged during the positive half-cycles, when voltage appears across resistor R , and will discharge into resistor R during the negative half-cycles, when no voltage appears across the resistor, thus tending to smooth out, or filter, the fluctuating direct current. Such a capacitor is known as a *filter capacitor*. It stores up voltage when it is present, and releases the voltage into the circuit



① Without capacitor.

② With capacitor.

Figure 54. Effect of filter capacitor.

when it is needed. Figure 54 shows the voltage appearing across resistor R , both with and without a filter capacitor in the circuit. It will be seen that the addition of a filter capacitor alone is not enough to

remove completely the fluctuations or ripple; in fact, no amount of capacitance, however large, would completely eliminate this ripple. However, if a filter circuit is added to the half-wave rectifier, as shown by the complete circuit (fig. 55), a satisfactory degree of filtering can be obtained. In this circuit, capacitors C_1 and C_2 are both filter capacitors, and fulfill the function described above. Inductor L is a filter choke having high reactance at the a-c frequency and a low value of d-c resistance. It will oppose any current fluctuations, but will allow direct current to flow unhindered through the circuit. The two filter

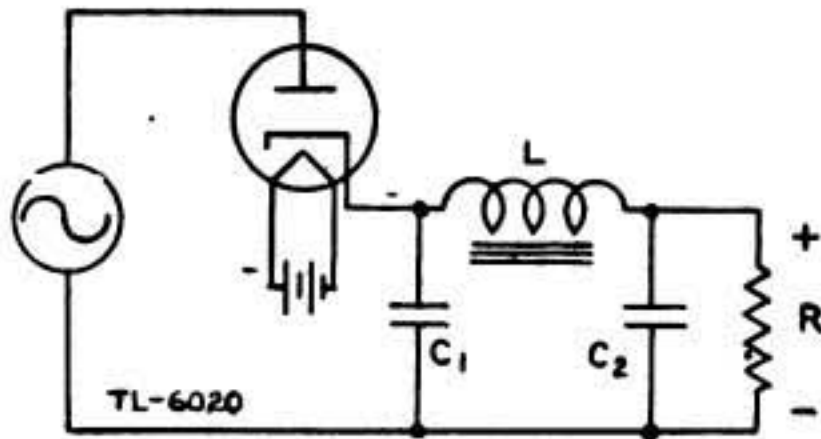


Figure 55. Filter circuit added to half-wave rectifier.

capacitors C_1 and C_2 bypass the ripple voltage around the load resistor R , while choke coil L tends to oppose the flow of any ripple current through the resistor.

d. The disadvantage of the half-wave rectifier is that no current flows during the negative half-cycle. Therefore, some of the voltage produced during the positive half-cycle must be used to filter out the ripple. This reduces the average voltage output of the circuit. Since the circuit is conducting only half the time, it is not very efficient. Consequently, the full-wave rectifier, so called because it rectifies on both half-cycles, has been developed for use in the power supply circuits of modern

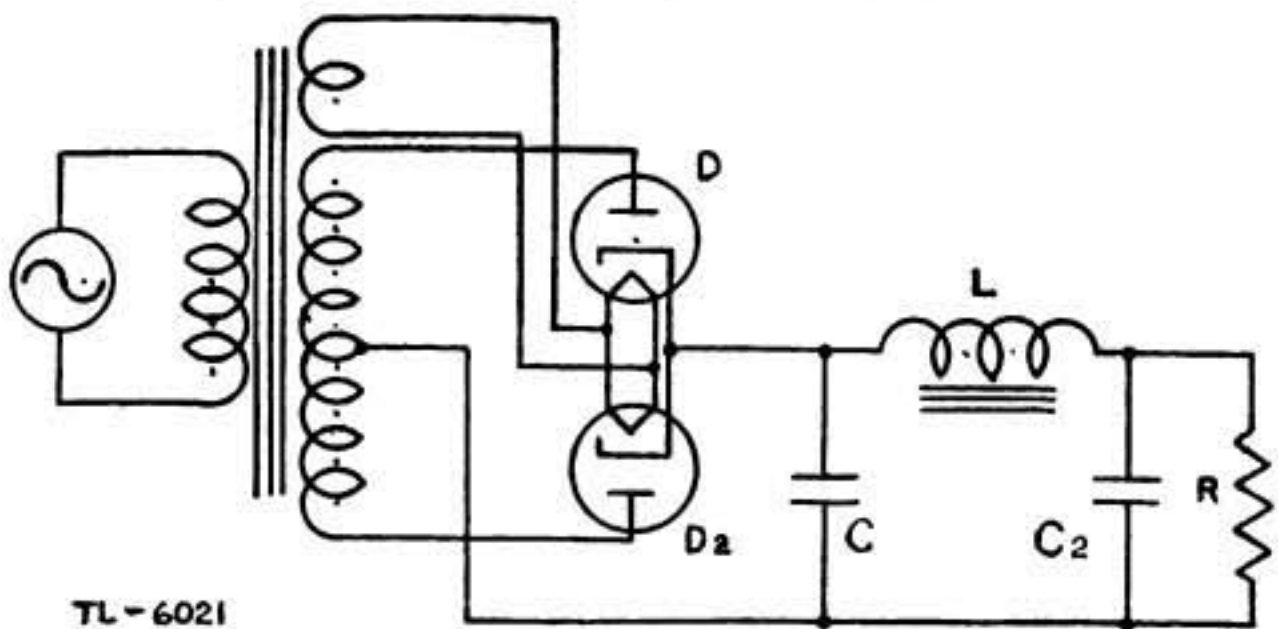


Figure 56. Full-wave rectifier circuit.

receivers and transmitters. In the full-wave rectifier circuit shown in figure 56, two diodes are used, one conducting during the first half-cycle and the other during the second half-cycle.

e. In the circuit of figure 56, the transformer has a center-tapped secondary winding, so that diode D_1 is connected to one half of this winding, while diode D_2 is connected to the other half. Resistor R is the load resistor common to both diodes. Capacitors C_1 and C_2 and inductor L form the filter circuit. During one half-cycle, the plate of diode D_1 will be positive with respect to the center tap of the transformer secondary winding, while the plate of diode D_2 will be negative; consequently, diode D_1 will conduct while diode D_2 will be nonconducting. During the other half-cycle, D_1 will be negative and nonconducting while D_2 will be positive and conducting. Therefore, since the two diodes take turns in their operation, and one of them is always conducting, current flows through the load resistor during *both* halves of the cycle. This is *full-wave rectification*.

f. If no filter circuit were used in the full-wave rectifier circuit of figure 56, the d-c output voltage across the load resistor R would appear

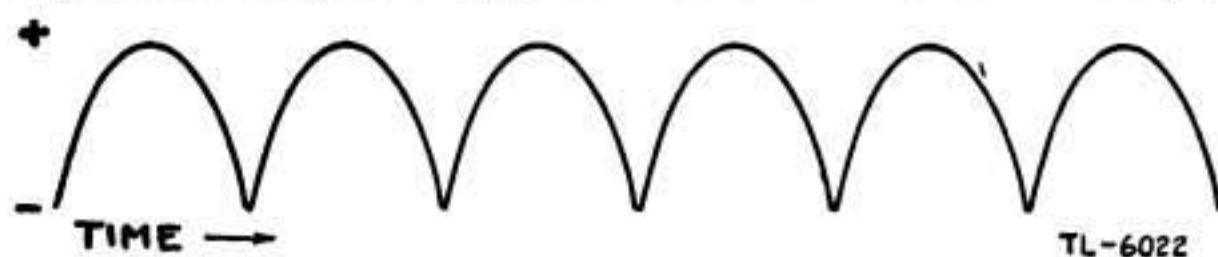


Figure 57. Output of a full-wave rectifier.

as in figure 57. Obviously, this voltage waveform is much easier to filter than the half-wave rectifier output, and the action of the capacitors and inductors in smoothing out this waveform is the same as for the half-wave rectifier voltage.

g. The circuit shown in figure 56 is the basis for all a-c operated power supplies used to furnish the d-c voltages required by transmitters and receivers. Note that the heater voltage for each of the two diodes is taken from a special secondary winding on the transformer.

36. Diode Characteristic Curves

a. The plate-current plate-voltage curve shown in figure 50 is an important characteristic of the diode vacuum tube, because it shows the amount of current that a diode will pass for any given plate voltage. Different types of diodes may have slightly different characteristic curves. All of these curves, however, indicate one important fact: the load, or plate, current is not proportional to the applied, or plate, voltage. For this reason Ohm's law is strictly applicable only to small increments, or changes, of currents and voltages. In general, current-voltage relations in vacuum-tube circuits are studied by means of experimentally obtained characteristic curves.

b. The curved portions, or bends, in the graph of figure 50 are the result of certain variations in the action of the diode. When the plate voltage is low, the electrons nearest the cathode are repelled back to the

cathode by the accumulated emitted electrons which are a little farther from the cathode, and only those electrons which are nearest the plate are attracted to the plate. This repelling effect around the cathode is known as the *space charge*. For intermediate values of the plate potential, the space charge in the vicinity of the cathode is reduced by the attraction of more electrons to the positively charged plate, and any increase in plate potential produces an appreciable increase in current, as shown by the curve of figure 50. For large values of plate potential, when the space charge is completely removed, the number of electrons reaching the plate per second is limited by the number emitted per second by the cathode, and is independent of plate potential. This latter condition is referred to as *saturation*, and a place along the curve (point *S* in fig. 50) is called the *saturation point*.

37. Operation of Triode

a. The *triode* differs in construction from the diode only in the addition of another element, called the *grid*. The grid is a cylindrical structure made of fine wire mesh, which is placed between the cathode and the plate of the tube so that all the electrons leaving the cathode must pass through it in order to reach the plate. Figure 58 is a drawing

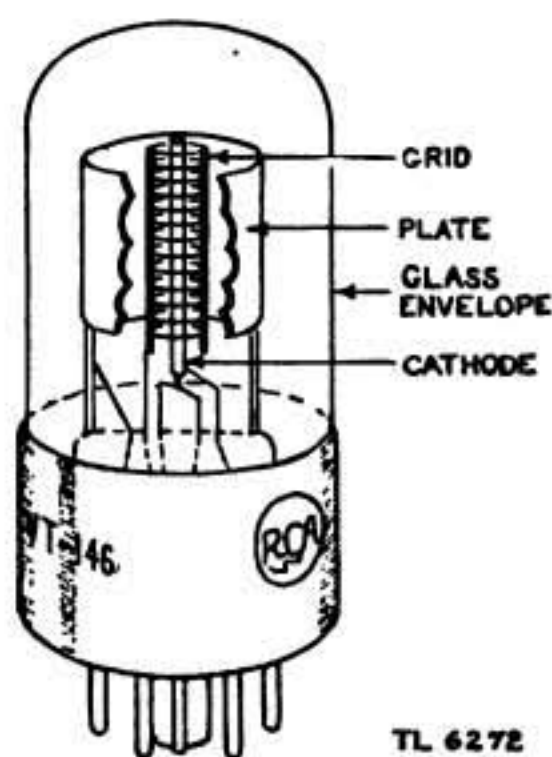


Figure 58. Typical triode.

which shows the arrangement of the grid, cathode, and plate in a typical triode. The grid is placed considerably closer to the cathode than is the plate, and consequently will have a very great effect on the electrons which pass through it.

b. If a triode is connected in a simple circuit, as shown in figure 59, the action of the grid can be studied. When a small negative voltage (with respect to the cathode) is put on the grid, there is a resultant change in the flow of electrons within the vacuum tube. Since the electrons are negative particles of electricity, and like charges repel one

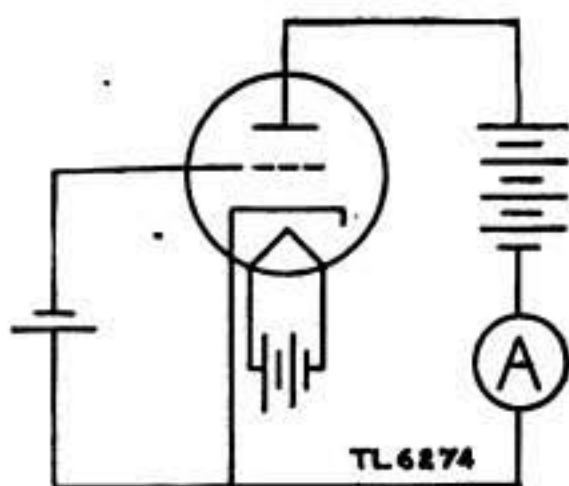


Figure 59. Triode with a small negative voltage on the grid.

another, the negative voltage on the grid will tend to repel the electrons emitted by the cathode, and thus tend to prevent them from passing through the grid on their way to the plate. However, since the plate is considerably positive with respect to the cathode, its attraction for the electrons is sufficiently strong to enable some of them to pass through the grid and reach the plate in spite of the opposition offered them by the negative voltage on the grid. Thus, a small negative voltage on the grid of the tube will reduce the electron flow from the cathode to the

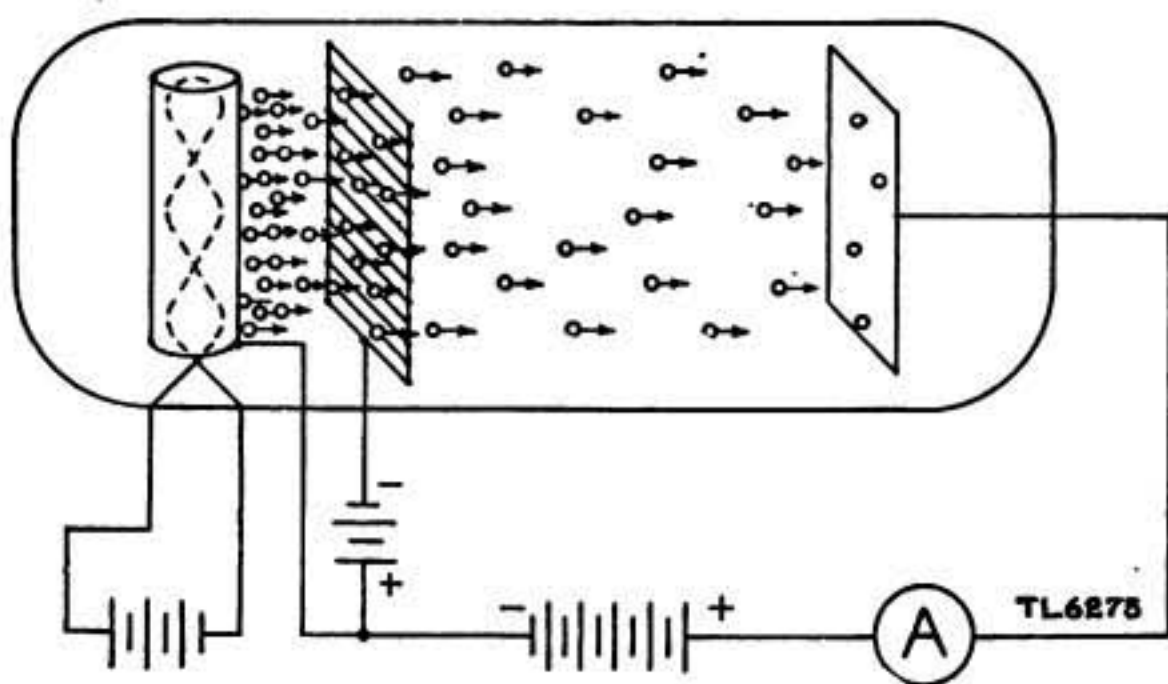


Figure 60. Effect of negative grid on plate-current flow.

plate (fig. 60), and consequently will reduce the value of plate-current flow between the cathode and the plate of the tube.

c. If the plate current in the circuit of figure 59 is measured by means of meter *A*, while holding the plate voltage constant and making the grid of the tube gradually more negative with respect to the cathode, the plate current will vary as shown in the *grid-voltage plate-current curve* of figure 61. Such a curve is also known as an $E_G - I_P$ characteristic curve. From this curve, it can be seen that as the grid of the tube is made more negative, less plate current will flow, since the more negative the grid the fewer electrons it permits to pass on to the plate. In the case of this particular tube (type 6C5), it will be noted from the characteristic curve that if the grid is made sufficiently negative (-10

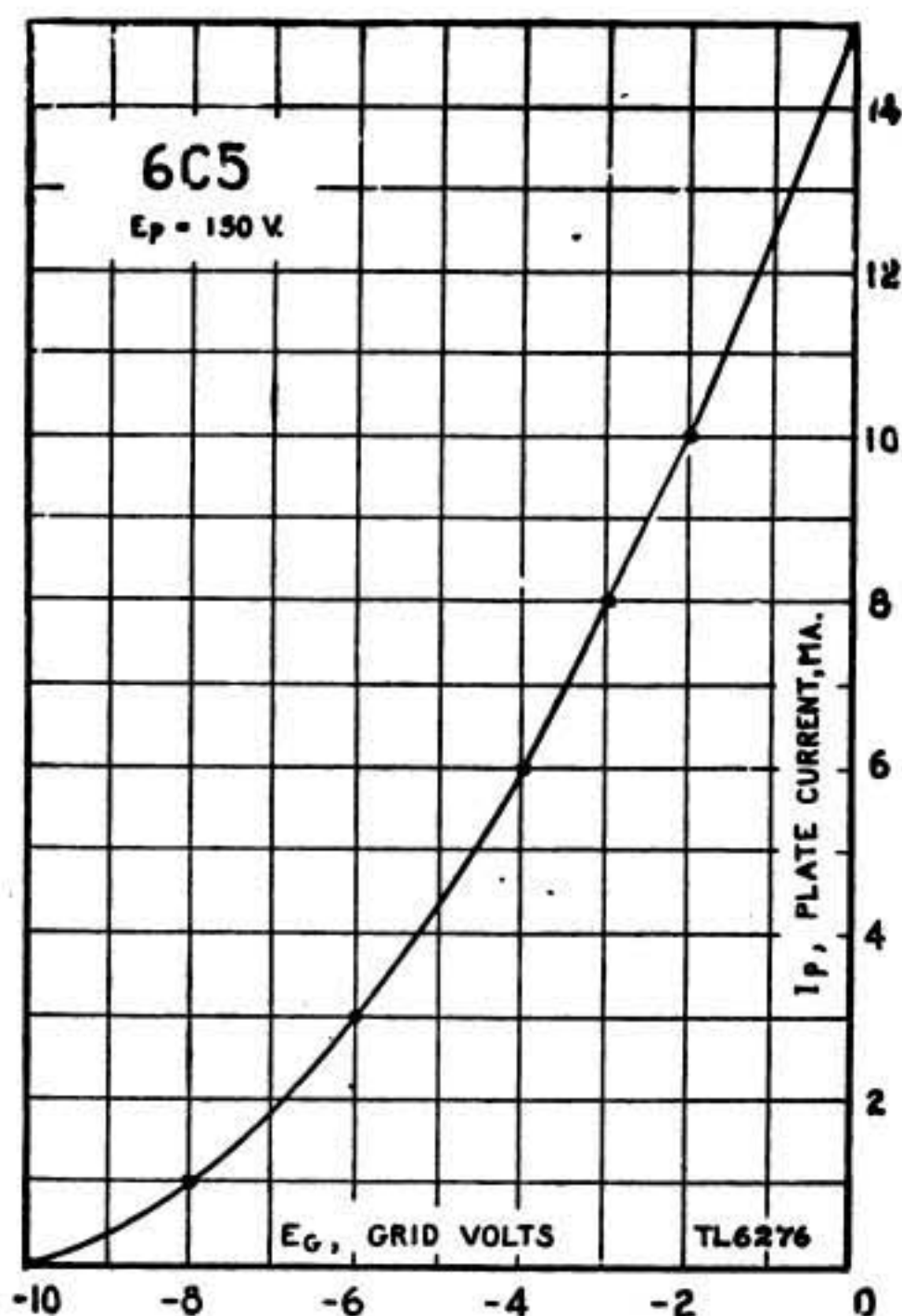


Figure 61. Grid-voltage plate-current curve.

volts), the plate current drops to zero. Thus, this value of negative grid voltage has cut off the flow of electrons within the tube. A negative voltage which is applied to the grid of a tube to hold its plate current flow at a given value is known as the *grid-bias voltage*, or more simply, the *bias*; that value of grid bias which will cut off the flow of plate current is called the *cut-off bias* for that tube. Since the plate current in a tube increases as the plate voltage is increased, the bias required to cut off plate current flow will increase as the plate voltage applied to the tube is increased.

d. The triode is now connected in a circuit (fig. 62) where an a-c (signal) voltage is applied to the triode, in addition to the grid-bias voltage. The a-c signal source is adjusted so that it applies 1 volt of a-c voltage to the circuit. Since the signal source and the 3 volts of negative bias are in series, on the positive half-cycle of the a-c signal there will be -2 volts applied to the grid with respect to the cathode ($+1 - 3 = -2$); on the negative half-cycle there will be -4 volts on the grid of the tube ($-1 - 3 = -4$). From the grid-voltage plate-current curve shown in figure 61, it can be seen that when there is no a-c signal

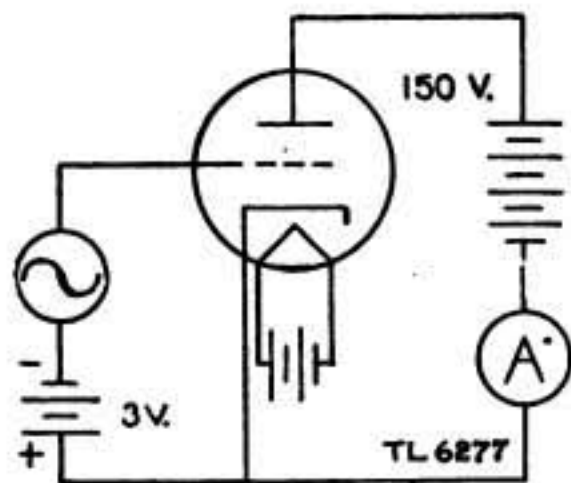


Figure 62. Triode with an a-c signal on the grid.

applied to the tube, the plate current will be fixed at 8 milliamperes by the 3 volts of bias supplied by the bias battery. When the a-c signal is applied to the tube, on the positive half-cycles there will be — 2

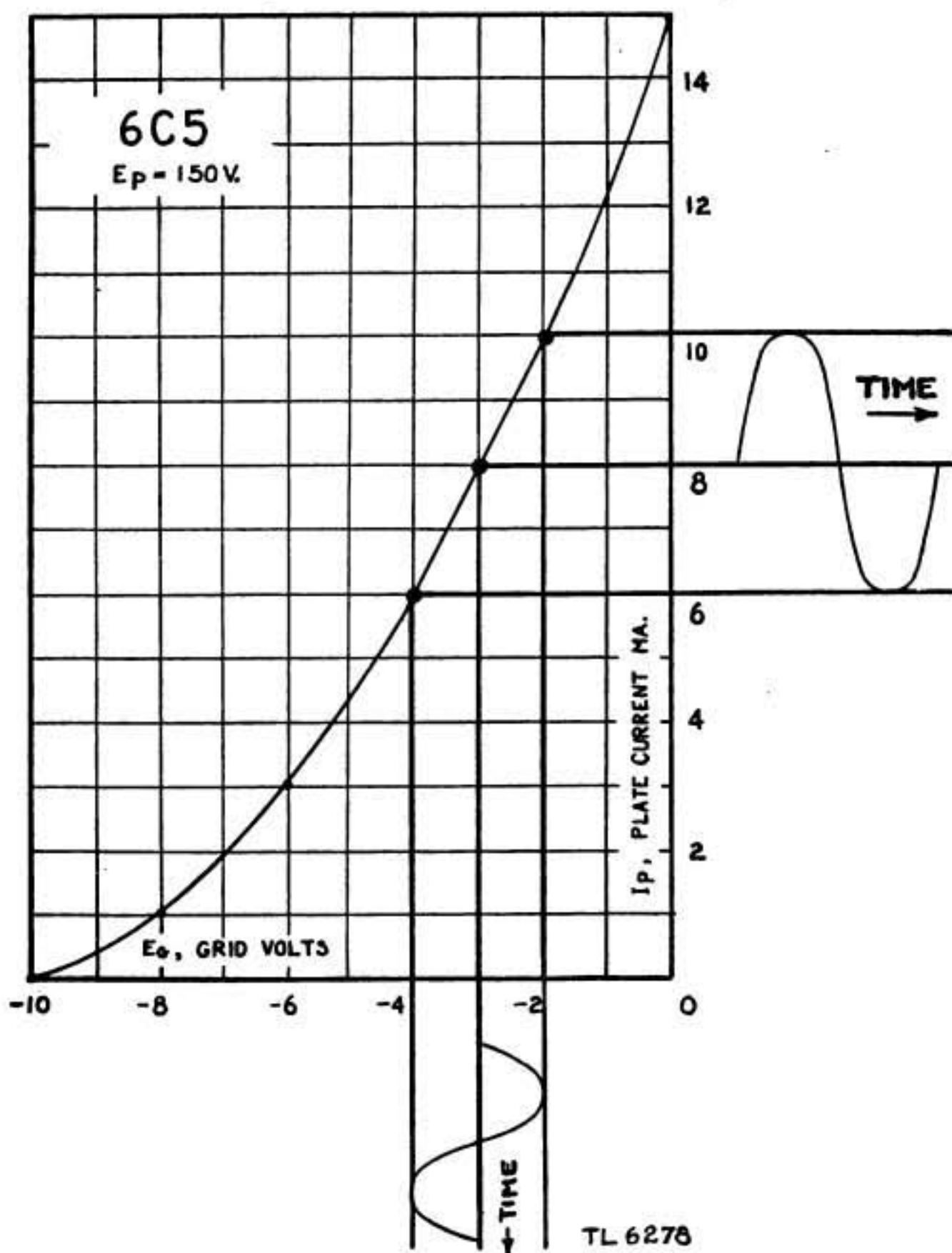


Figure 63. Plate current waveform resulting from an a-c grid voltage.

volts on the grid of the tube and the plate current will increase to 10 milliamperes; but on the negative half-cycles there will be -4 volts on the grid and the plate current will decrease to 6 milliamperes. Thus, a 1-volt a-c signal will cause a plate current change of 4 milliamperes in this tube. This can be demonstrated graphically by showing the a-c voltage waveform on the grid-voltage scale of the $E_G - I_P$ characteristic curve, and plotting the plate-current waveform on the plate-current scale of the graph (fig. 63).

e. An examination of figure 63 will show that the waveform of the plate current variation is an exact reproduction of the waveform of the a-c voltage applied to the tube. By carrying this process further, it can be shown that if the negative bias is increased to 5 volts, so that the grid voltage varies from -4 to -6 volts over the a-c cycle, the plate current change will vary from 3 to 6 milliamperes, showing a total change of only 3 milliamperes. If the negative bias voltage is increased to 9 volts, so that the grid voltage varies from -8 to -10 volts over the a-c cycle, then the plate current change will be only 1 milliampere. From this it can be seen that if the negative bias is increased, there is a resultant decrease in the plate current change for a given signal input. This method of controlling the output of a tube by varying the bias voltage is often used as a means of volume control, as will be shown later in the study of radio receiver. It should be noted, however, that if the grid voltage is increased to too high a negative value (fig. 64①), there is noticeable distortion of the output plate current wave. Distortion also results if the cathode temperature is lowered to such a degree that the emission is insufficient (fig. 64②). A distorted output is generally, but not always, objectionable.

38. Triode Circuits; Plate Loads

a. In order to make use of the variations in the plate current of a

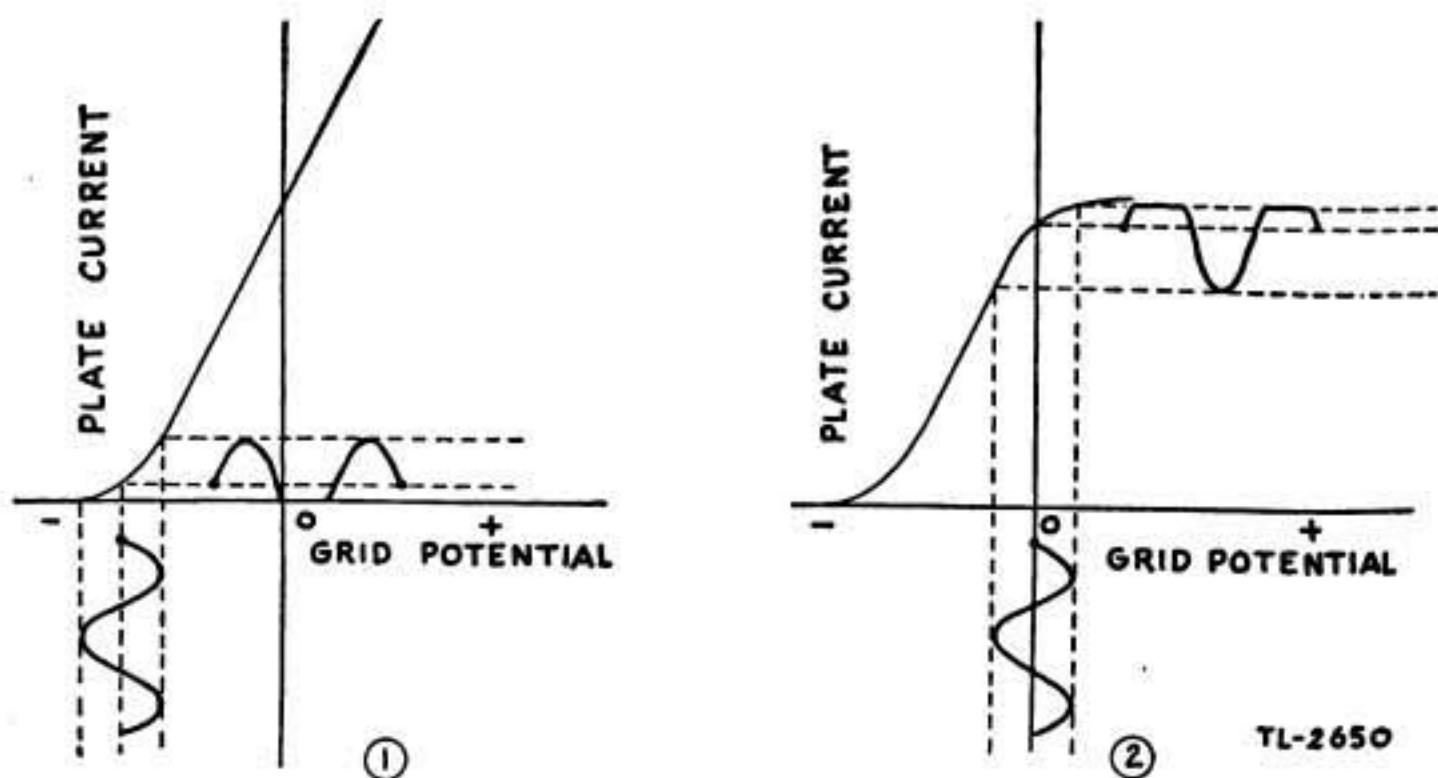


Figure 64. Distortion due to high grid bias and low cathode temperature.

triode due to variations in grid voltage, some sort of a device must be present in the plate circuit of the tube to act as a load. This plate load can be a resistor, an inductor, or a tuned circuit.

b. A typical triode circuit with a resistor used as a plate load is shown in figure 65. If the tube in this circuit is biased at -3 volts and the applied a-c signal voltage to the grid is 1 volt, the plate current variation of 4 milliamperes will produce a voltage variation of 40 volts across the 10,000-ohm resistor. On the positive half-cycles, the negative voltage of 2 volts applied to the grid causes a current flow of

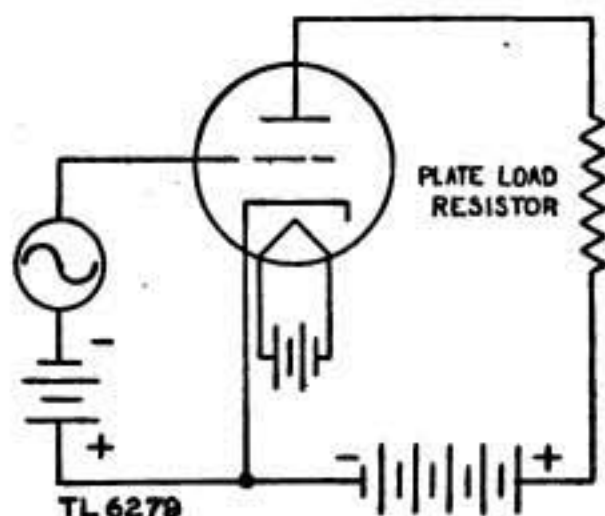


Figure 65. Triode using a resistor as a plate load.

10 milliamperes through the plate load resistor, thus producing a voltage drop of 100 volts (by Ohm's law). On the negative half-cycles, the negative voltage of 4 volts applied to the grid causes a current flow of 6 milliamperes through the plate-load resistor, and a corresponding voltage drop of 60 volts. The difference between these two voltage drops, or 40 volts, is the *voltage variation* in the plate circuit produced by the a-c voltage applied to the grid. Thus it can be seen that a signal voltage change from -1 to $+1$ (or a total change of 2 volts) can produce a voltage change of 40 volts in the plate circuit; in other words, the original (grid) signal voltage has been amplified 20 times. This process is the basis for all vacuum-tube amplification.

c. The use of a resistor as the plate load of a vacuum tube has one disadvantage: its resistance will reduce the actual d-c voltage applied

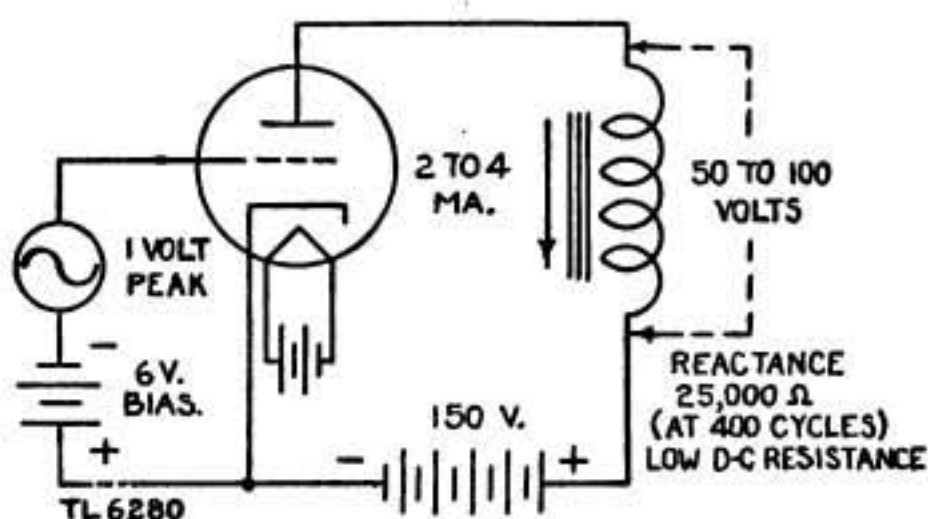


Figure 66. Triode using an inductor as a plate load.

to the plate of the tube, and so reduce the amplification of the tube. To overcome this loss in plate voltage, inductors are often used as plate loads of vacuum-tube circuits (fig. 66). By choosing an inductor which has a high value of reactance at the frequency of the alternating current, a large voltage will be built up across the reactance, because of the plate-current changes in the tube. However, the d-c plate voltage applied to the plate of the tube will be quite high, since the d-c resistance of an inductor may be very small, and consequently the amplification of the tube will be increased.

d. If it is desired to amplify a signal of a given frequency, a tuned circuit which resonates at this frequency may be used for a plate load (fig. 67). Since the impedance of such a circuit will be very high at the resonant frequency, the signal voltage appearing across the tuned

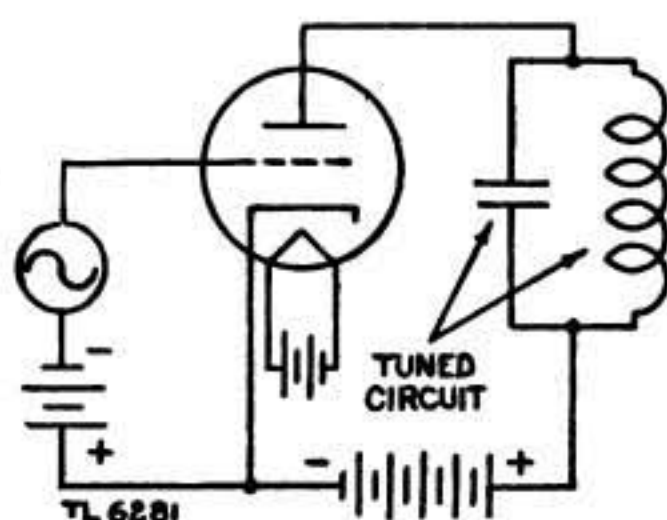


Figure 67. Triode using a tuned circuit as a plate load.

circuit will also be high. By using a tuned circuit as the plate load for a vacuum tube, it is possible to obtain the amplification *only at the resonant frequency of the tuned circuit*. The circuit of figure 67 is typical of the r-f amplifier circuits used in radio transmitters.

39. Triode Circuits; Biasing Methods

a. There are several different methods of obtaining a negative grid-bias voltage for a triode. The simplest of these is the *fixed bias*, where a suitable negative voltage is obtained from a fixed source, such as batteries or a rectifier power supply. Examples of this type of bias are shown in figures 59, 62, and 65.

b. A vacuum-tube circuit can be arranged to produce its own bias, and such a method is known as *self-bias*. One type of self-biasing, called the *cathode-return-resistor bias*, is shown in a triode-amplifier circuit in figure 68. In this circuit, the plate current from the battery flows through the cathode resistor on its way through the tube and back to the battery through the plate-load resistor. Since the current is flowing through the cathode resistor toward the cathode, there will be a voltage drop across this resistor which will make the grid *negative with respect to the cathode*. This is the proper condition for biasing. The

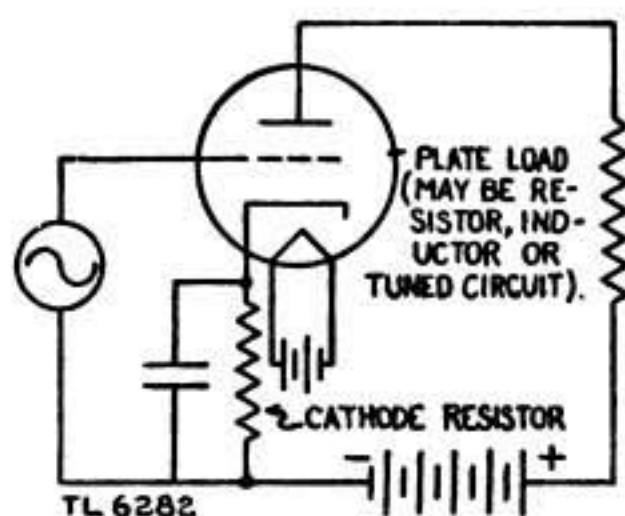
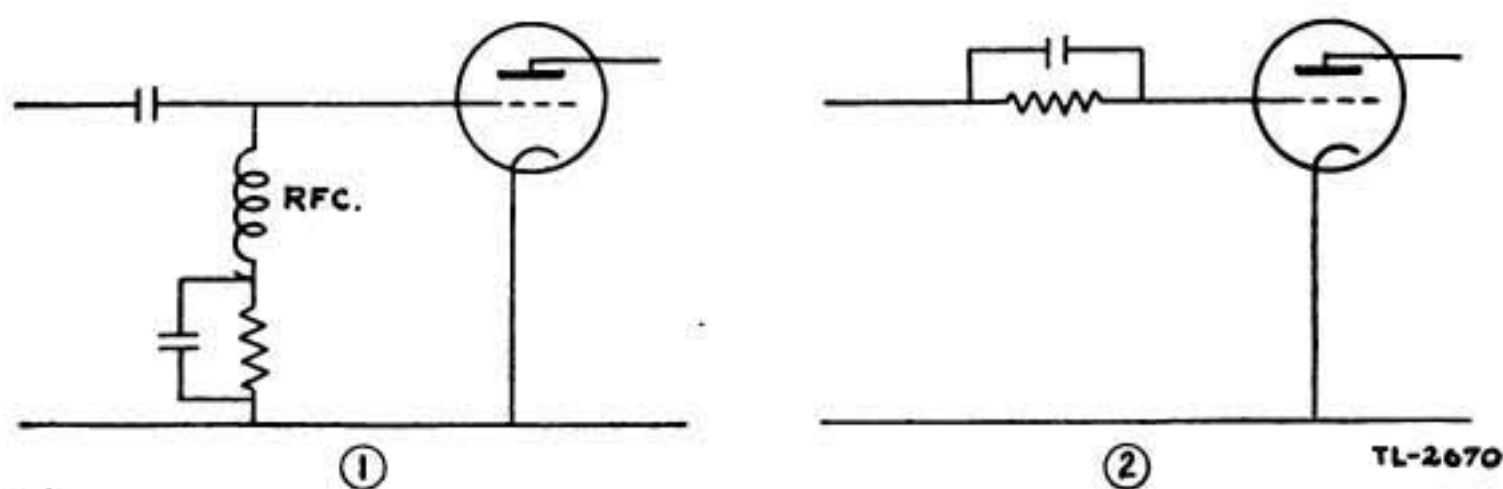


Figure 68. Triode amplifier circuit with self-bias.

convenience of this type of bias is obvious, since it eliminates the need for a separate source of bias voltage. For this reason, cathode-resistor bias is widely used in both transmitters and receivers. Omission of the shunt capacitor, or too small a value of this capacitor, produces *degeneration* (par. 102c) as a result of the variations of grid bias which then accompany the a-c pulsations of the plate current. This capacitor should have a low reactance at the signal frequency, thus keeping the cathode resistor from dropping the a-c signal voltage as well as the d-c plate voltage.

c. Another form of self-bias is called the *grid-leak bias*, and is used under conditions where grid current flows. Two examples of this type of bias are shown in figure 69. The bias results from the drop in potential across the resistor when grid current flows on positive a-c signal swings. This resistor is called a *grid-leak*. The capacitor across the leak offers a low impedance to alternating current, so that the bias is



① Shunt arrangement. ② Series arrangement.

Figure 69. Grid-leak bias circuits.

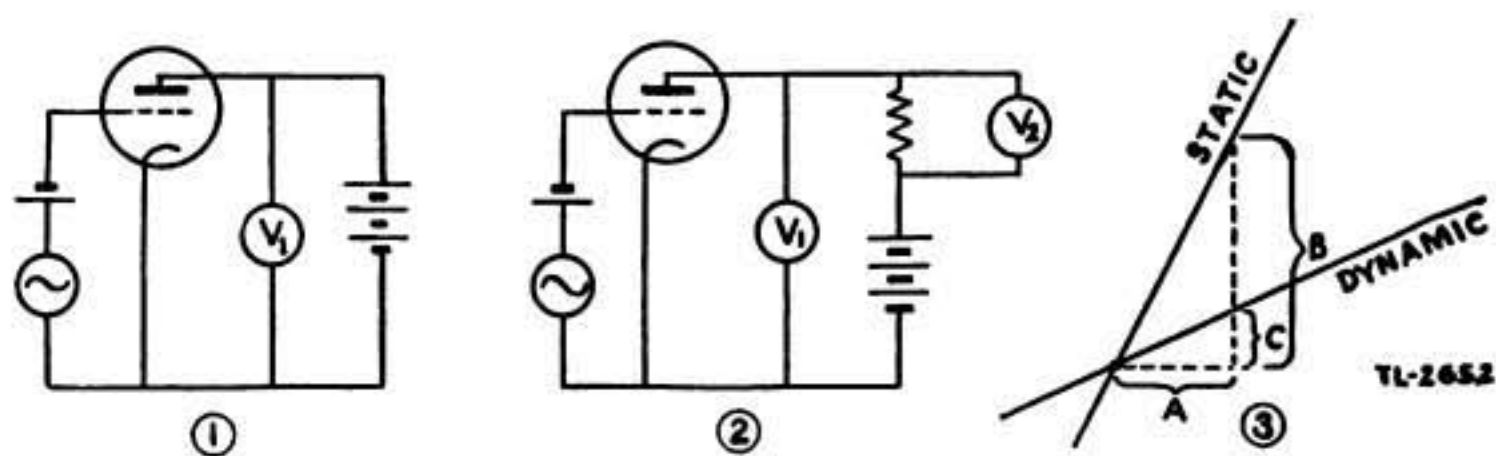
essentially steady in character and is a function of only the magnitude, or size, of the grid current. A disadvantage of grid-leak bias is that if for any reason the excitation is removed, the bias is removed also, and the plate current may assume dangerous proportions, causing damage to the vacuum tube.

d. To combine the advantage of grid-leak and battery (or fixed) bias, transmitter amplifiers often use a combination of both types in series.

Some types of amplifier tubes are conveniently designed, as regards bias supply, to operate with the grid at cathode potential; these are known as *zero-bias tubes*.

40. Triode Characteristic Curves

a. There are two general types of characteristic curves for triodes. One is for the case of no load in the plate circuit, and is called the *static characteristic curve*; the other is for the case of a load in the plate circuit, and is known as the *dynamic characteristic curve*. Use has already been made of the static curve in figures 61, 63, and 64, where the tube was operating without a plate load. In practice, however, the output of a tube feeds into some sort of load which can be represented by a resistance value (assumed to be the equivalent of the load). This results in dynamic characteristic curves that reflect more accurately the operating conditions of the tube. A comparison of the static and dynamic curves, with the two circuits that are used to obtain each, is shown in figure 70③. The difference in the slope of the two curves is due to the fact that the plate-to-cathode potential for no load is constant regardless of the plate current, whereas with a load in the plate circuit the potential across the load (and consequently the plate-to-cathode potential) varies with the current. Assume that the normal operating point is the same for the tube with or without external load; that is, regard the operating point as the point of intersection of the two curves of figure 70③. Without an external load (fig. 70①) on a positive



① Without external load. ② With external load
③ Corresponding characteristics.

Figure 70. Triode characteristic curves.

swing of signal potential A (fig. 70③), the plate current rises by an amount B . With an external load (fig. 70②), the increase in current which follows a positive grid swing is in turn accompanied by a potential drop ($I \times R$) across the load resistor (as read by voltmeter V_2). Thus the potential available across plate to cathode within the tube (as read by voltmeter V_1) is reduced; and the consequent increase in current C is less than it was under the no load condition. On the negative half-cycle of the signal voltage, the plate current is reduced,

and the potential drop across the load is less than it is when no signal is applied. Thus the voltage across the tube rises, so that the available plate-to-cathode potential exceeds the corresponding value under the no load condition. A typical set of static plate-current grid-voltage curves for various plate potentials is shown in figure 71. Many handbooks on vacuum tubes confine the characteristics illustrated to *families* of curves of the static type.

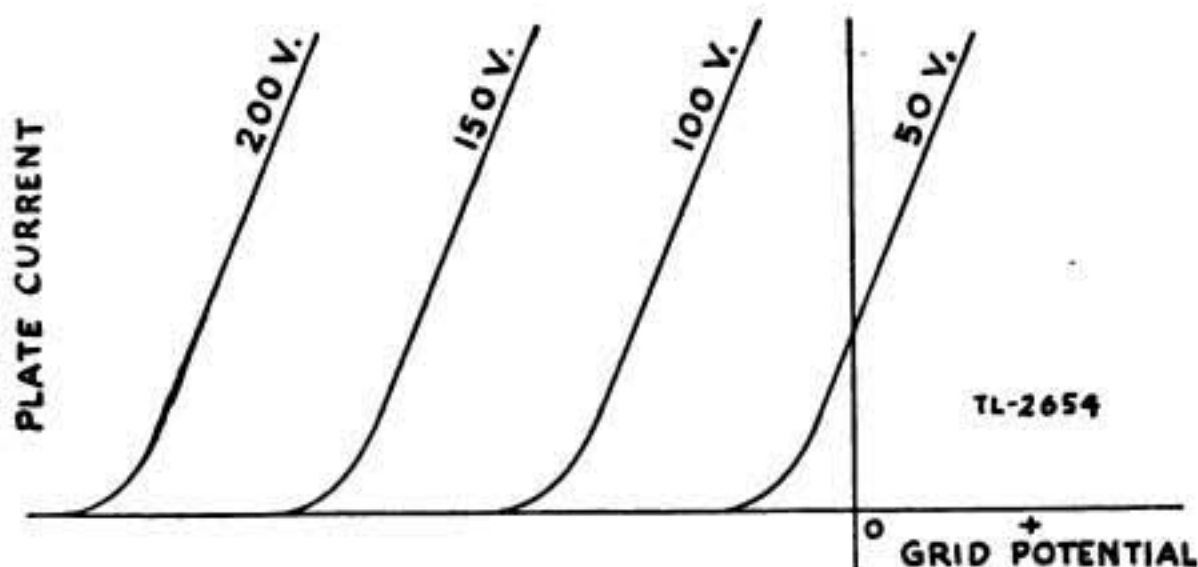


Figure 71 Plate-current vs. grid-potential curves for triode.

b. Observe from the set of static characteristic curves of figure 72, that of the three quantities, grid potential, plate potential, and plate current, any two will determine the third. Thus, corresponding to a plate current of 10 milliamperes and a plate potential of 50 volts, the

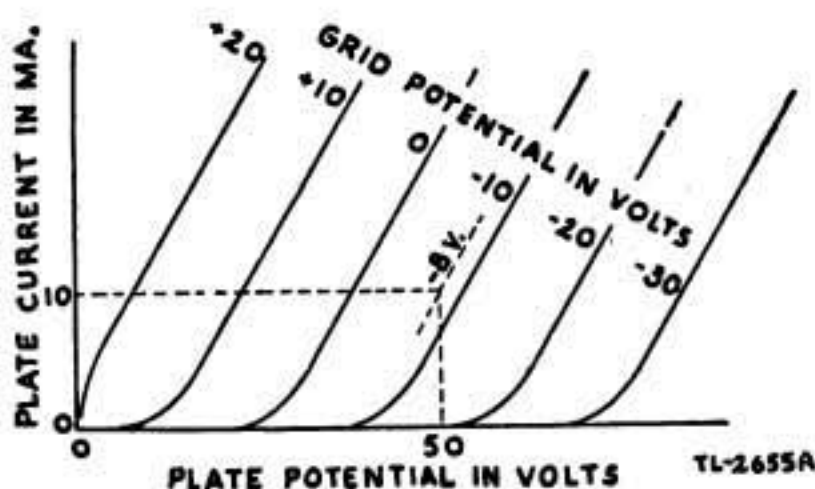


Figure 72. Plate-current vs. plate-voltage curves for a triode.

required grid potential is -8 volts. Suppose it is desired to obtain these same relations—plate current, 10 milliamperes; plate potential, 50 volts; and grid potential -8 volts—with a load resistance of 4,000 ohms. This requires a total plate-supply potential of $50 + [4,000 \times (10/1,000)]$ volts = 90 volts, 50 across the tube and 40 across the load resistance. The current in the load resistance follows Ohm's law, that is, the current through the resistance is proportional to the potential across it. This proportionality can be represented by a straight line on the current-voltage graph of figure 73. The line is determined by any two points on it, two convenient points being P and

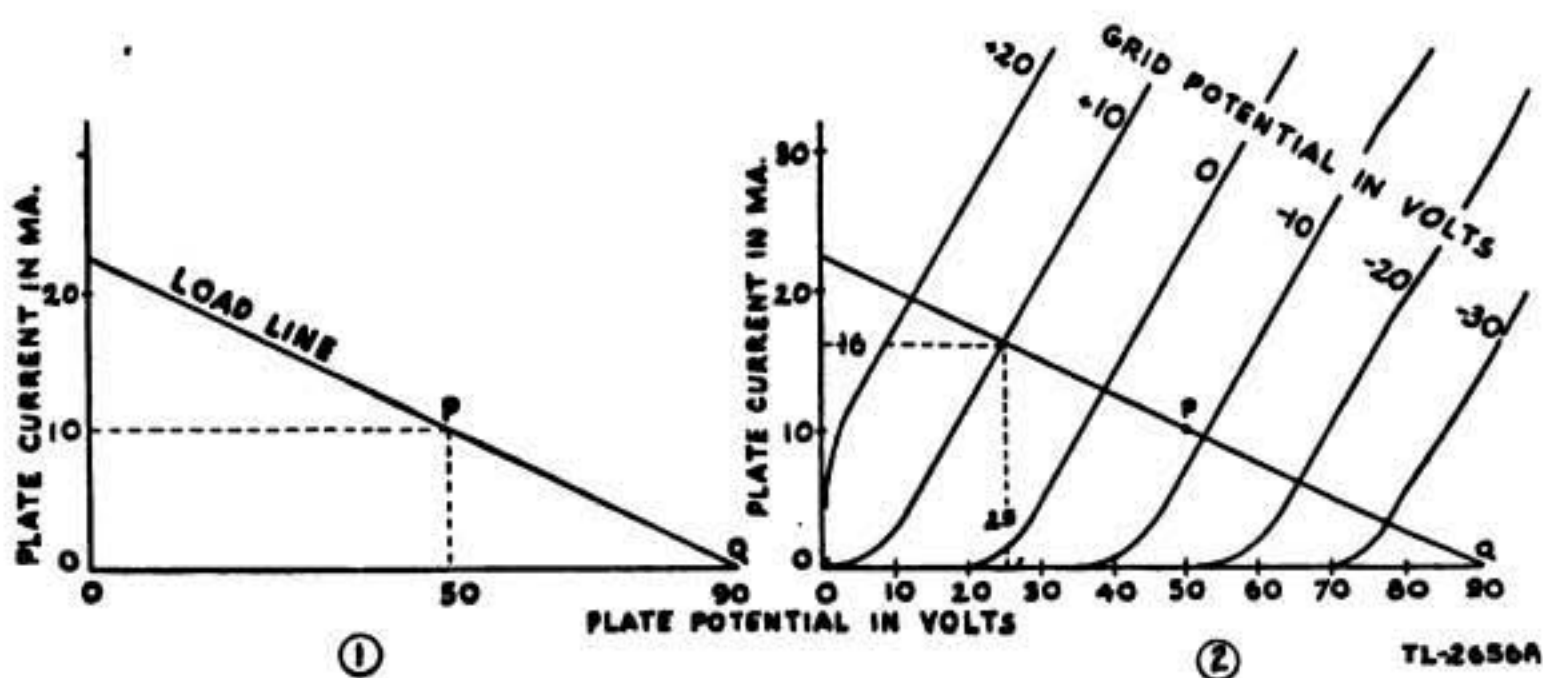


Figure 73. Load line for a triode.

Q , as in figure 73①. P is for a current of 10 milliamperes and a voltage drop across the resistance of 40 volts (50 volts across the tube); Q is for zero current and zero drop across the resistance (90 volts across the tube). If P is taken as the normal operating point, the grid swing due to an impressed signal voltage will cause variations along this load line in both directions from P . Corresponding to an instantaneous grid potential of 10 volts, the plate current, plate voltage, and voltage across the load can be found by following the 10-volt characteristic to where it intersects the load line. From the curves of figure 73②, this yields 16 milliamperes plate current, 25 volts plate potential, and $90 - 25 = 65$ volts drop across the load. The family of plate-current plate-potential curves is thus useful in determining the limitations of a particular tube under various operating conditions. A particular tube can be selected to fit certain circuit constants, or vice versa, with the aid of the information contained in the vacuum-tube characteristics.

41. Special Characteristics of Vacuum Tubes

a. Since many different types of vacuum tubes are used in modern radio circuits, it is important to have different means of classifying these tubes according to the performance which may be expected of them. Among these characteristics, as they are called, are the *amplification factor*, the *mutual conductance*, and the *plate resistance* of the tube.

b. The *amplification factor* μ , or mu , of a tube is the ratio of the plate-voltage change and the grid-voltage change required to produce the same plate-current change in the tube. For example, if the plate voltage of a tube must be increased by 20 volts in order to increase the plate current as much as would a 1-volt change of grid voltage, then the tube has an amplification factor of 20. The amplification factor of a tube is stated for a given set of operating conditions, such as grid-bias voltage, plate voltage, etc., since the amplification factor will change if

these conditions are changed. The amplification factor of a tube gives a theoretical approximation of the maximum voltage amplification which can be expected from the tube under given operating conditions.

c. The *mutual conductance*, or *transconductance*, of a tube is a characteristic from which the power sensitivity can be estimated, since it determines what plate-current change may be expected from a given grid-voltage change under a given set of operating conditions. Mutual conductance, or transconductance, is the ratio of a small change in plate current to the change in grid voltage producing it. It is measured in *mhos*, which is simply the word ohm spelled backwards and with an "s" added. For example, if a grid voltage change of 1 volt produces a plate-current change of 1 ampere in a given tube under certain operating conditions, the tube will have a mutual conductance of 1 mho. But since very few tubes will stand a plate current flow of 1 ampere (receiving tubes draw only a few milliamperes of plate current), it is more convenient to rate mutual conductance in *micromhos* (or millionths of a mho). Thus, if a tube has a mutual conductance of 5,000 micromhos, a 1-volt change in grid voltage will produce a 5 milliampere change in plate current.

d. The *plate resistance* of a tube is simply the resistance between the cathode and plate of the tube to the flow of alternating current. It is the ratio between a small change in plate voltage and the corresponding change in plate current. For example, if a 10-volt change in plate voltage produces a 1-milliampere change in plate current, the plate resistance of the tube is 10,000 ohms.

42. Interelectrode Capacitance

The inherent capacitance between grid and plate elements of a triode is of sufficient importance at high frequencies to require special consideration in radio circuits. Where this capacitance is undesirable, it can be counteracted by introducing a neutralizing circuit which presents r-f potentials equal in magnitude but opposite in phase to those occurring across the interelectrode capacitance, with the result that the effects of the interelectrode capacitance are nullified. The extra circuit complications can generally be avoided by the use of tetrodes or pentodes, 4- and 5-element tubes, respectively, which are particularly designed to have low interelectrode capacitance. The grid-plate capacitance of an ordinary receiving triode runs about 3 micromicrofarads. This represents a capacitive reactance of 53,000 ohms at 1 megacycle and only 530 ohms at 100 megacycles. Tetrodes and pentodes offer corresponding reactances of about 16,000,000 ohms at 1 megacycle and 160,000 ohms at 100 megacycles.

43. Tetrode

a In an effort to reduce the grid-plate capacitance within the tube (par. 42), a fourth element was added to the conventional triode. This

fourth element is called a *screen grid*, and is placed between the grid and the plate of the tube. A typical screen grid, or tetrode (4-element) tube connected in a circuit is shown in figure 74. Observe the changes in this circuit due to the addition of the screen grid. Notice that the screen grid is operated at a positive voltage somewhat lower than that

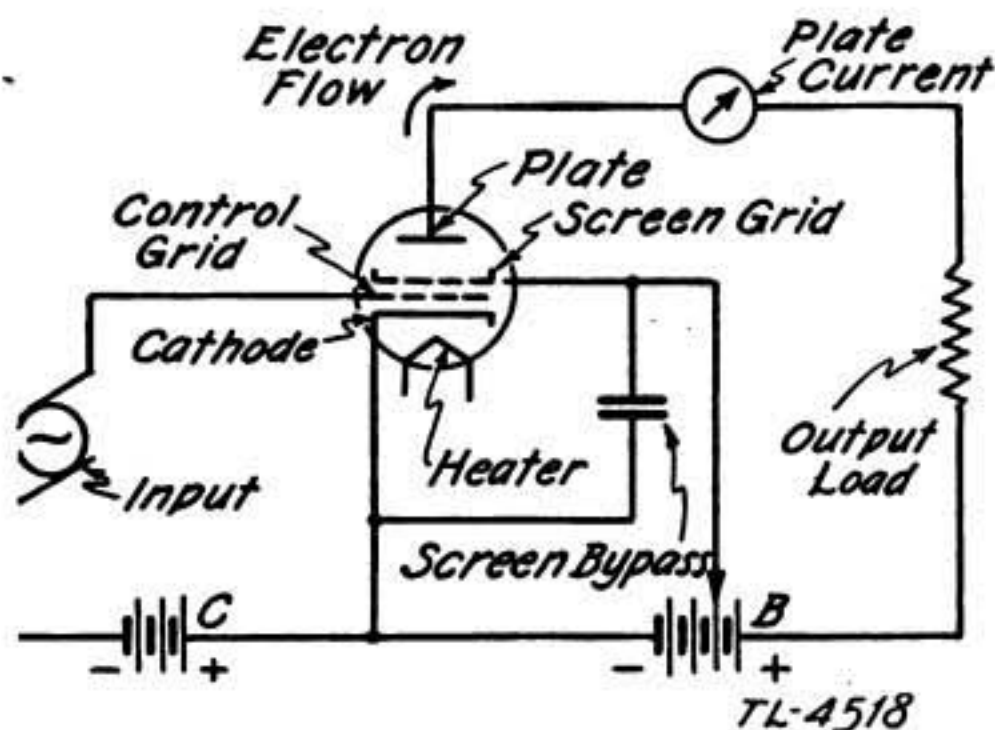


Figure 74. Tetrode amplifier circuit.

applied to the plate. Since it is operated at a positive voltage, the screen assists the plate in attracting electrons from the cathode. Some of these electrons will be attracted to this grid by the positive voltage on it, thus causing screen current to flow in the circuit. However, since the construction of the screen grid is similar to that of the control grid, most of the electrons will pass through the spaces between its wires on to the plate, because of the attraction of the higher positive voltage on the plate. Since the screen grid is bypassed to the negative side of the circuit (bypassed to ground) by a screen bypass capacitor having a small reactance at the signal frequency, it acts as a shield or screen between the grid and the plate, and thus effectively reduces the capacitance between these two electrodes.

b. If the screen grid in this circuit is not operated at a positive voltage, but is connected to the cathode, it will have a controlling effect on the electron flow, similar to that of the control grid of the tube, thus reducing the plate-current flow to a value too small for satisfactory operation. The value of a positive voltage on the screen grid of a tetrode will determine to a large extent the maximum value of current which will flow in the plate circuit. Thus, improper screen voltages can cause faulty operation in tetrode amplifier circuits.

c. The tetrode has several advantages over the triode, in addition to its greatly reduced grid-plate capacitance. Among these are a higher amplification factor, and greater power sensitivity. In general, tetrodes can be used for the same purposes as triodes. Since they were devel-

oped to overcome the need for neutralization in r-f amplifier circuits, tetrodes have been widely used in the r-f amplifier stages of radio receivers and transmitters.

44. Pentode

a. Although the tetrode would seem to be an ideal tube, since it overcomes the disadvantage of the higher grid-plate capacitance of the triode and, at the same time, is capable of providing higher amplification in a circuit than is the triode, the effect known as *secondary emission* limits its application to a great extent. The pentode, or 5-element tube, was developed to overcome the effect of secondary emission. If a tetrode is operated at fairly high plate and screen voltages, and large values of signal voltage are applied to its control grid, the electrons strike the plate with sufficient force to knock loose other electrons already on the surface of the plate. These other electrons, known as *secondary electrons*, are attracted by the positive voltage on the screen grid. When secondary emission occurs, the screen gets more than its share of the available electrons, while the number reaching the plate is greatly reduced. Thus, the screen current will increase while the plate current will decrease, causing a reduction in the amplification of the tube and distortion in its output.

b. If a third grid is placed between the screen grid and the plate of the tetrode, and is connected to the cathode so that it will have the same charge as the electrons, it will force any secondary electrons back to the plate, since like charges repel one another. This third grid is called the *suppressor grid*, since it suppresses the effects of secondary emis-

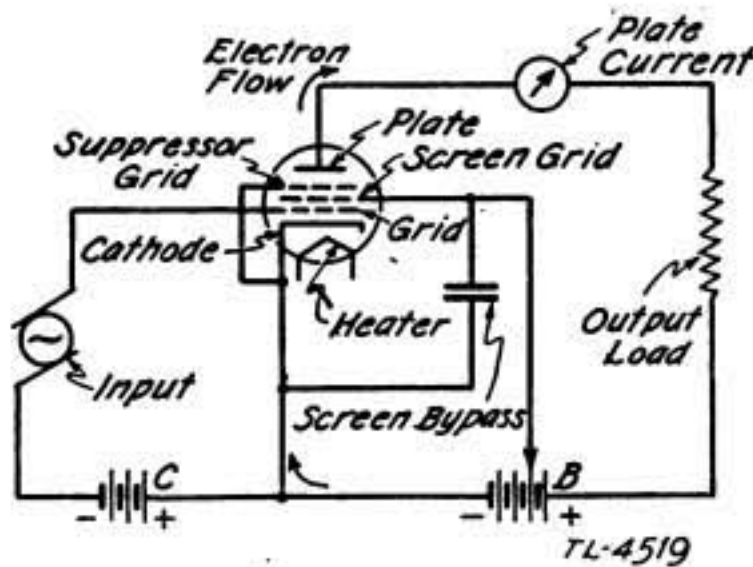


Figure 75. Pentode amplifier circuit.

sion by preventing the flow of secondary electrons to the screen. The suppressor grid will not reduce the electron flow to the plate, even though it is operated at a negative potential. This is because it is placed so close to the plate that the attraction of the positive voltage on the plate is much greater than any tendency on the part of the suppressor grid to repel the electrons.

c. A pentode used with a typical amplifier circuit is shown in figure 75. Note that the only difference between this circuit and the tetrode amplifier circuit of figure 74 is the addition of the suppressor grid. Both the cathode and the suppressor grid are at the same potential.

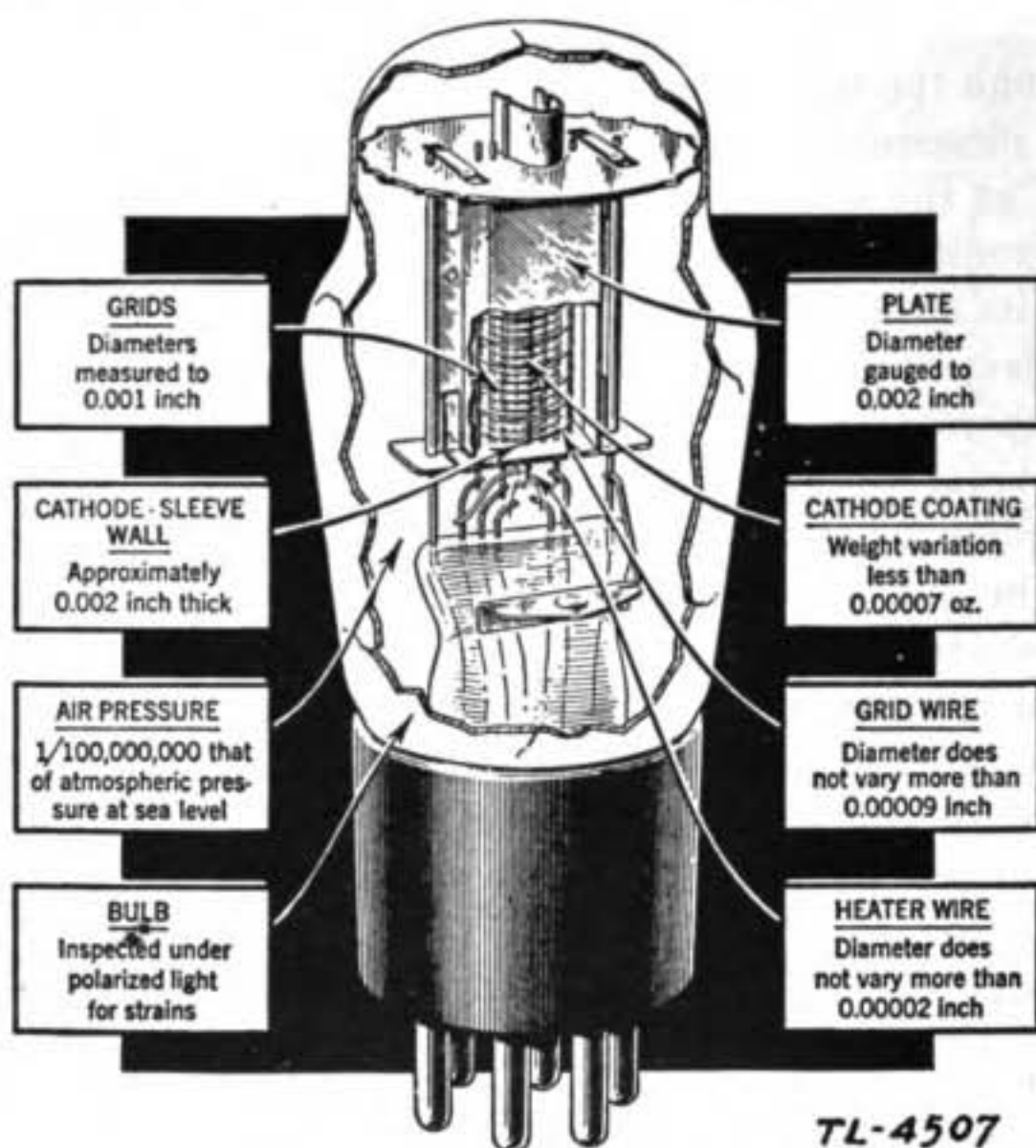


Figure 76. Typical Pentode.

d. The construction of a typical pentode power-amplifier tube is shown in figure 76. Such a tube is suitable for use in the power-output stages of radio receivers.

45. Variable-mu Tube

a. The amplification of a tube is controlled by varying the bias voltage applied to the grid, but normally the range of this control is limited by the value of cut-off bias for the tube. It is most desirable in the r-f amplifiers of receivers, the gain of which is controlled by automatic volume control, to be able to vary the amplification over a much wider range, so that large values of signal voltage (strong signals) may be handled. To permit this increased range of gain control, the variable-mu tube has been developed. This type of tube is also known by several other names, two of which are *supercontrol* and *remote cut-off*. The only difference in construction between variable-mu tubes and normal, or *sharp cut-off*, types, is the spacing of the turns of the grid. In sharp cut-off tubes, the turns of the grid wire are equally spaced, while in remote cut-off types the grid turns are closely spaced on both ends

and widely spaced in the center. When small negative voltages are applied to the grid of a variable- μ tube, the electrons will flow through all the spaces in the grid. As the negative voltage is increased, however, the electrons will no longer be able to pass through the narrow spaces on the ends of the grid structure, though they will still be able to pass through the relatively greater spaces at the center of the grid. A much greater value of negative voltage will thus be required to cut off the plate-current flow in this type of tube. This remote cut-off tube is so named because the cut-off bias value is greater than (remote from) the value required to cut off plate-current flow in tube of evenly spaced grid turns.

b. Figure 77 shows the $E_G - I_P$ curves for a typical sharp cut-off pentode and a typical remote cut-off pentode on the same graph. Note that the cutoff bias for the tube with the uniformly spaced grid is -6 volts.

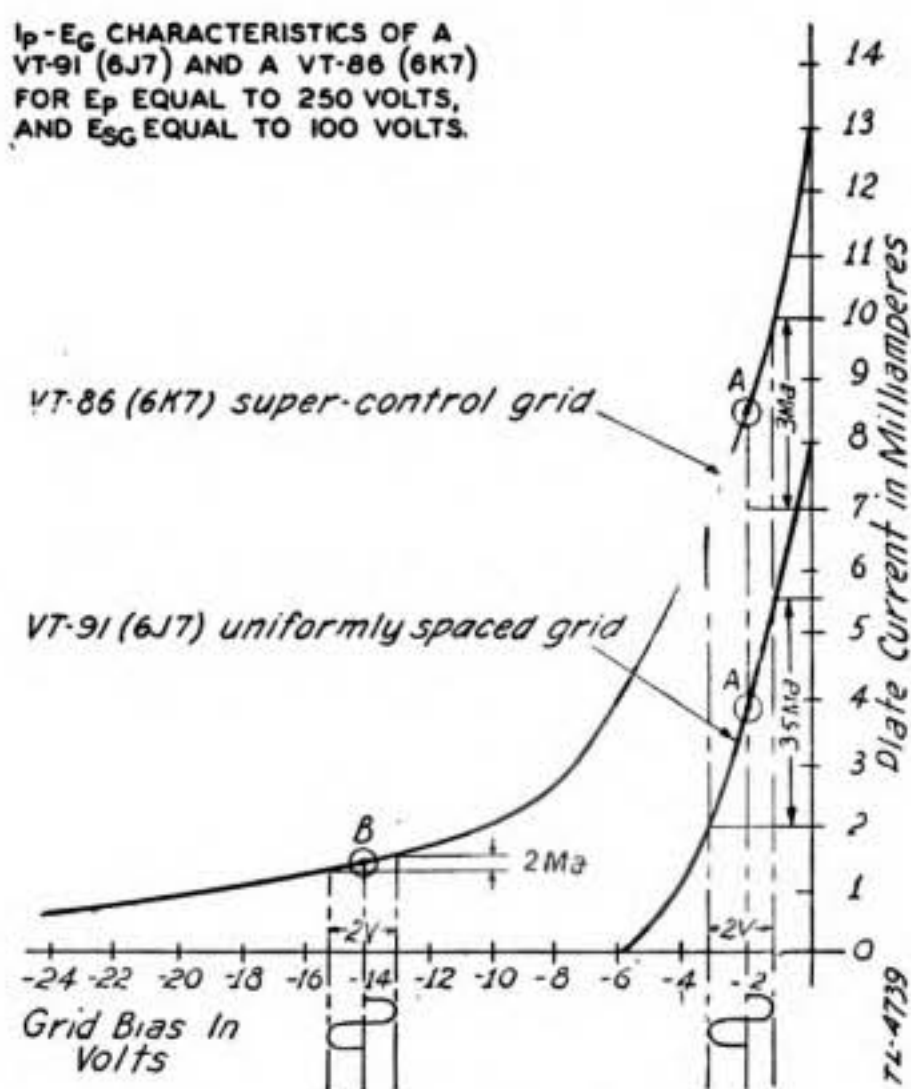


Figure 77. Comparison between a sharp cut-off pentode and a remote cut-off pentode.

Thus the range of gain control which can be effected by grid-bias variation, and the maximum value of signal voltage which can be applied to the grid, are both limited. But the curve for the supercontrol pentode shows that plate current still flows even at a grid bias of -24 volts. Thus, by the use of a variable- μ tube, both the range of gain control by grid bias variation and the value of signal voltage which can be handled by the grid have been extended several times.

c. Variable- μ pentodes are used in the r-f amplifier stages of practically all modern radio receivers. They are not generally used in a-f

amplifiers, however, because of extreme curvature, or nonlinearity, of their $E_G - I_P$ curves, which would result in distortion of the output voltage when large signal voltages were applied to their grids.

46. Beam-power Tube

a. In recent years a new type of power-amplifier tube has been developed. Compared with other tetrode and pentode power-amplifier tubes, this tube has the advantages of higher power output, higher power sensitivity, and higher efficiency. This type of tube is called the *beam-power tube*, since by its construction the electrons are caused to flow in a concentrated beam from the cathode, through the grids, to the plate. The only difference in construction between the beam-power tube and normal tetrodes and pentodes is that the spaces between the turns

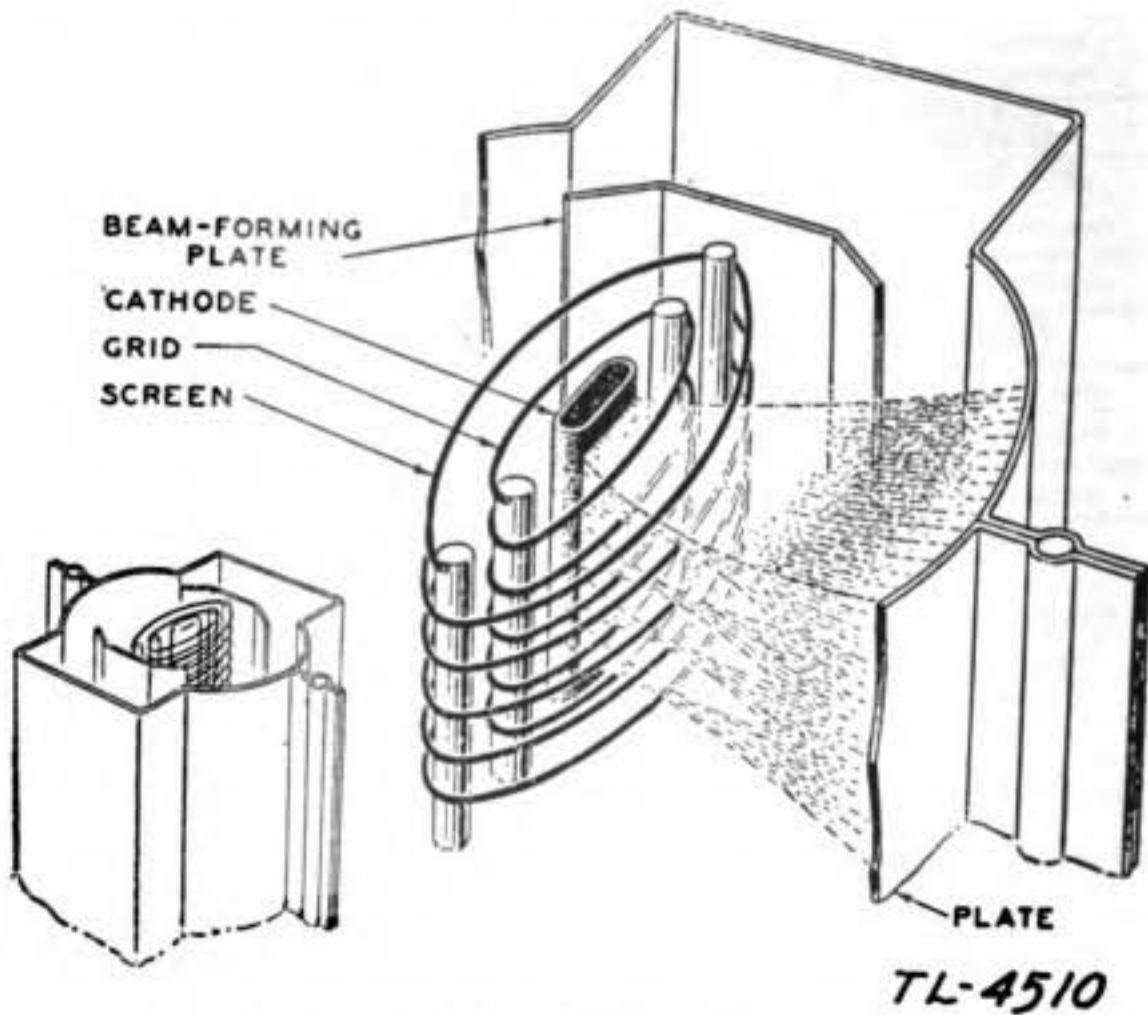


Figure 78. Internal structure of a beam-power tube.

of the several grids are lined up and two beam-forming plates are provided. Figure 78 shows the internal construction of a beam-power tetrode. Since the spaces between the turns of the grids are lined up, fewer electrons will strike the screen grid. The screen current will therefore be decreased, while the plate current will be increased. Since the power output of a circuit is proportional to the value of plate current flowing through the load, the power output will thus be increased. The two beam-forming plates are usually connected to the cathode and, having the same charge as the electrons, cause them to flow in a beam from the cathode, through the grids, to the plate. The placement of the beam-forming plates is such that it forces the electrons to flow through the desired portions of the grids, and prevents them from striking

the wires which support the grids. Thus, by causing the electrons to flow in a beam, the number of electrons reaching the plate can be increased, thereby greatly increasing the operating efficiency of the tube.

b. Figure 79 illustrates an a-f power-amplifier circuit using a beam-power tetrode. Notice that in this case the beam-forming plates are connected to the cathode inside the tube.

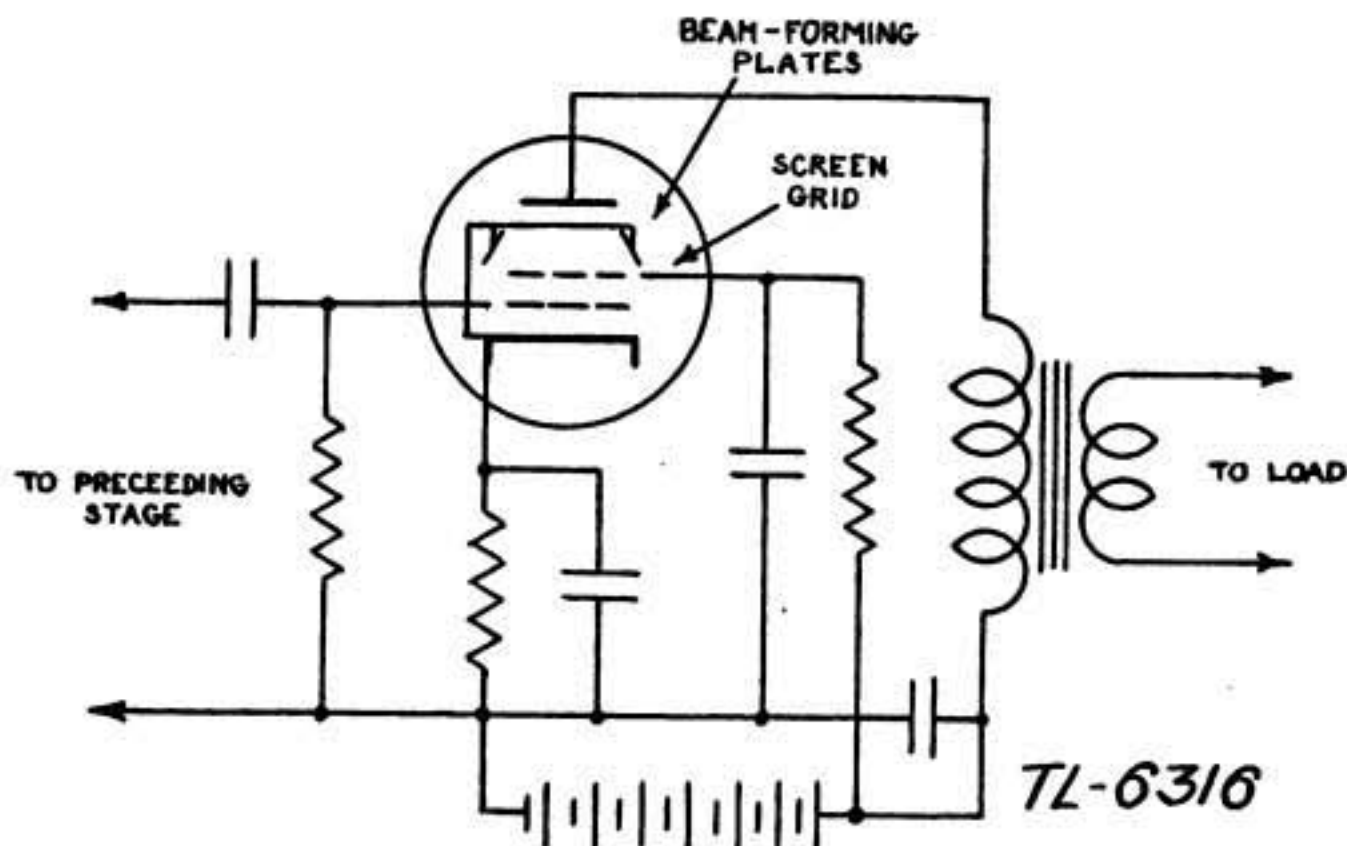


Figure 79. Beam-power tetrode, a-f power amplifier.

c. A beam-power tube operated at the same voltages as a normal tetrode or pentode type will provide more power output for a given value of signal (input) voltage than the latter, and have a much higher plate-circuit efficiency. Both beam tetrodes and beam pentodes are used in radio receivers and transmitters. In beam tetrodes, the effect of secondary emission is reduced to a minimum by the action of the beam, and the replacement of the beam-forming plates. Beam-power tubes are widely used as r-f and a-f amplifiers in radio transmitters, and as output a-f amplifiers in radio receivers.

47. Multi-element Tubes

a. In addition to the diodes, triodes, tetrodes, and pentodes which have been studied, there are many special types of vacuum tubes used in radio circuits; a large number of types are used which combine the electrodes of two or more tubes in one envelope. These complex tubes are usually named according to the equivalent single-tube types of which they are composed. Thus a twin triode contains the electrodes for two triodes in one envelope. Other complex tubes are *diode triodes*, *diode pentodes*, *triode pentodes*. One complex type has recently been introduced which combines the functions of *three* tubes within one envelope, namely, a diode, a triode, and a power-output pentode. *All of these tubes however complex follow the basic rules for tube operation.*

To understand the operation of any one of them in a circuit it is only necessary to consider the effect of the various electrodes on the flow of electrons within the tube.

b. The *pentagrid-converter tube* is a special type which has five grids, and is used in a certain stage of the superheterodyne receiver to take the place of two separate vacuum tubes. The pentagrid-converter tube is used for frequency conversion. (See sec. VIII.)

c. The *duplex-diode triode* and the *duplex-diode pentode* are two popular types of receiver tubes. In receiver circuits, one of the diodes is used together with the cathode as a diode-detector circuit, while the other diode is used together with the cathode to rectify the signal voltage in order to produce a source of automatic volume control. The triode or pentode section of such tubes is used as an a-f amplifier.

48. Directly and Indirectly Heated Cathodes

a. A cathode which is in the form of a filament directly heated by passing a current through it has the disadvantage of introducing a ripple in the plate current when alternating current is used for heating. The ripple is most objectionable if the plate and grid returns are made to one end of the filament. In figure 80 the resistor *AB* repre-

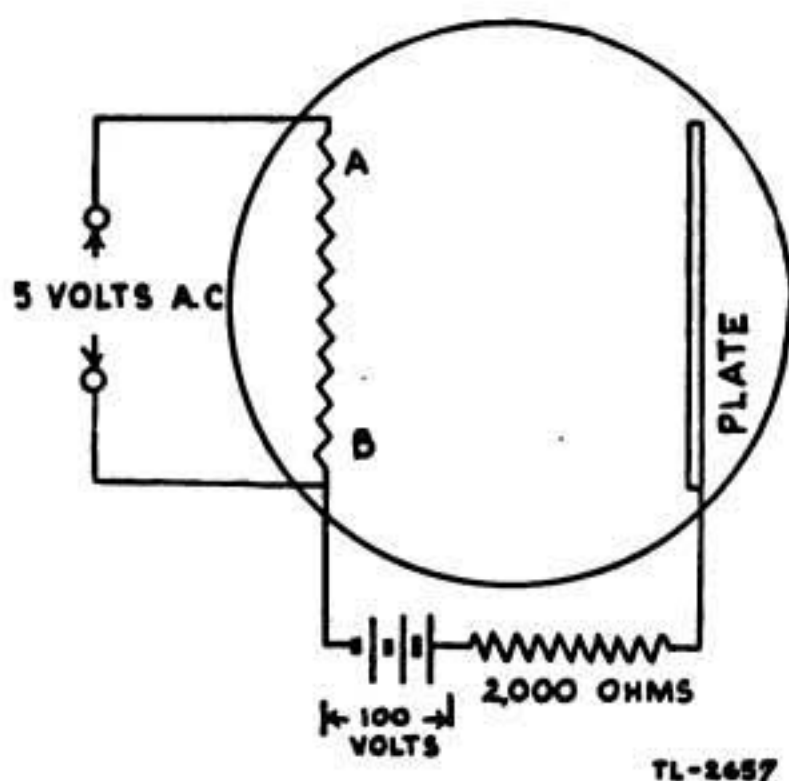


Figure 80. Directly heated cathode.

sents a filament which is heated by applying 5 volts of alternating current across it. When no current flows through the tube, the plate is maintained at a potential of 100 volts above that of point *B*. For a 5-milliampere steady plate current, the potential across the tube from *B* to the plate is always $100 - \left[2,000 \times \frac{5}{1,000} \right] = 90$ volts; whereas the potential from *A* to the plate varies from 85 to 95 volts, depending upon the potential of point *A* relative to point *B*. The total plate current rises and falls at the frequency of the filament

current. This condition is remedied to a large extent by connecting the grid and plate returns to the electrical center of the filament, as in figure 81① or ②. But even with a center-return arrangement, with a 60-cycle filament current, there is still present a 120-cycle modulation of the plate current. This double-frequency ripple arises from the effects on the plate current provided by the intermittent rise and fall of the filament temperature, the voltage drop in the filament, and the alternating magnetic field set up by the filament current. Temperature fluctuations in the filament are ordinarily negligible. The magnetic field about the filament serves to deflect the electrons from their normal paths; and, in effect, serves to reduce

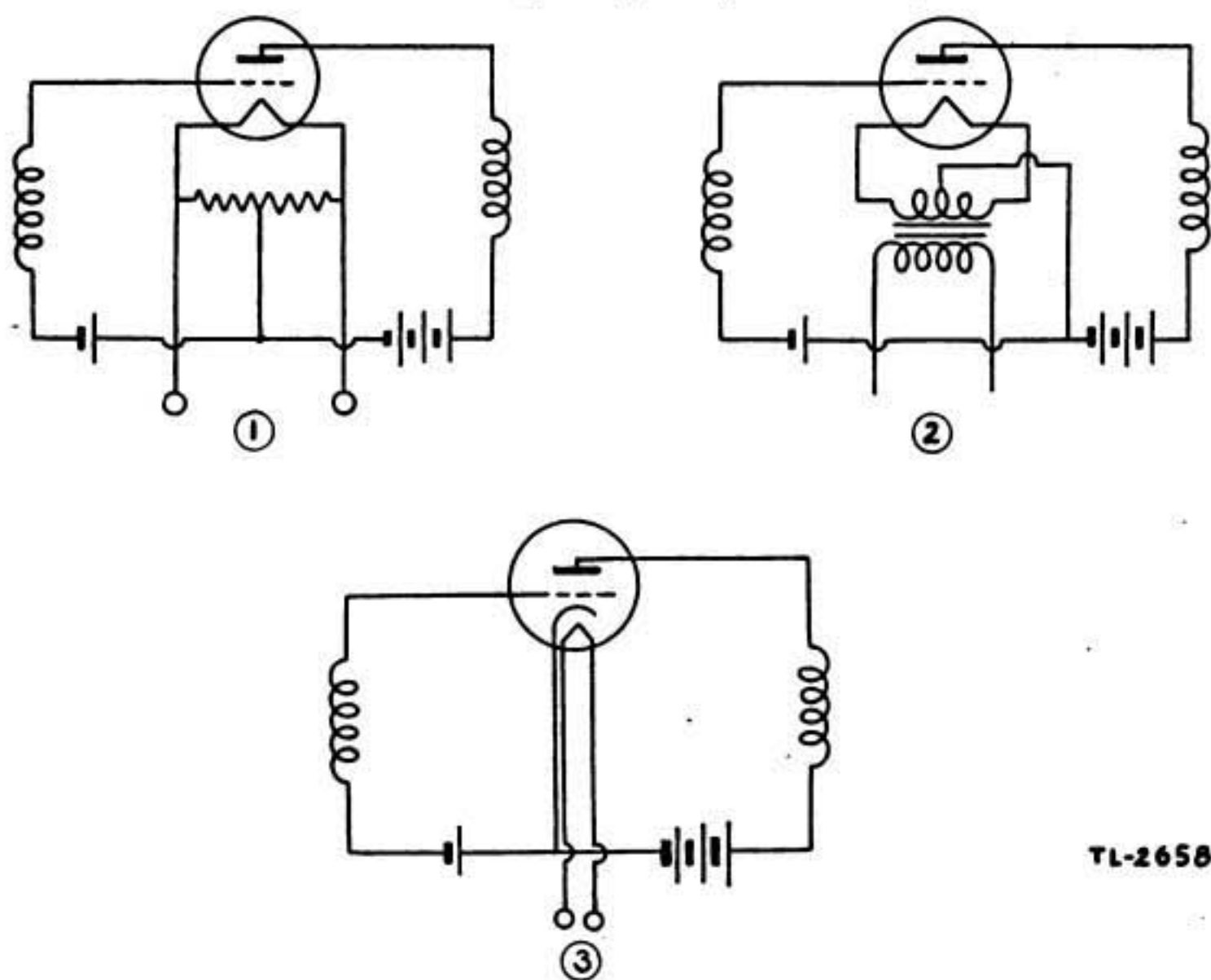


Figure 81. Methods of utilizing a-c filament supply.

the plate current. The resulting plate current is largest when the heating current is zero, that is, at intervals which occur at double the heating current frequency. With a voltage drop in the filament, the space current from the negative half of the filament exceeds that from the positive half, because of the manner in which space current varies with the electrostatic field across the tube. (Space current varies as the three-halves power of the plate potential.) The result is that each time the current is at a maximum in either direction in the filament, that is, at a frequency which is double the heating-current frequency, the space current is slightly greater than its value during those instants when the current through the filament is zero and the potential of the filament is uniform.

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b. In transmitting tubes and in the power stages of a receiver the signal currents are large, and the double-frequency ripple current is negligible in comparison. However, in all other receiver tubes, indirectly heated cathodes (fig. 81③) are necessary wherever a-c filament operation is desired. An indirectly heated cathode is formed by a metallic sleeve closely surrounding a heated filament and electrically insulated from the filament. The cathode is heated by radiation from the filament. Such an emitter is sometimes referred to as an equipotential cathode, since all parts of it are at the same potential. For purposes of simplicity, tube-heater elements and heater-power circuits are not shown in circuit diagrams throughout this manual.

SECTION V

VACUUM-TUBE DETECTORS

49. Detection

a. There are two general kinds of radio-frequency (r-f) signals that can be received by a radio receiver: *modulated* r-f signals which carry speech, music, or other audio sounds, and *continuous wave* (c-w) signals which are "bursts" of r-f energy conveying code. These types of r-f signals are described in more detail in sections XI and XII. The process whereby the intelligence carried by a r-f signal is extracted as an a-f (audio-frequency) signal is called *detection*, or *demodulation*.

b. The modulated r-f signal can be detected by any one of several types of vacuum-tube detectors: the simple *diode detector*, the *grid-leak detector*, the *plate detector*, or the *regenerative detector*. The c-w signal is generally detected by the *heterodyne detector*.

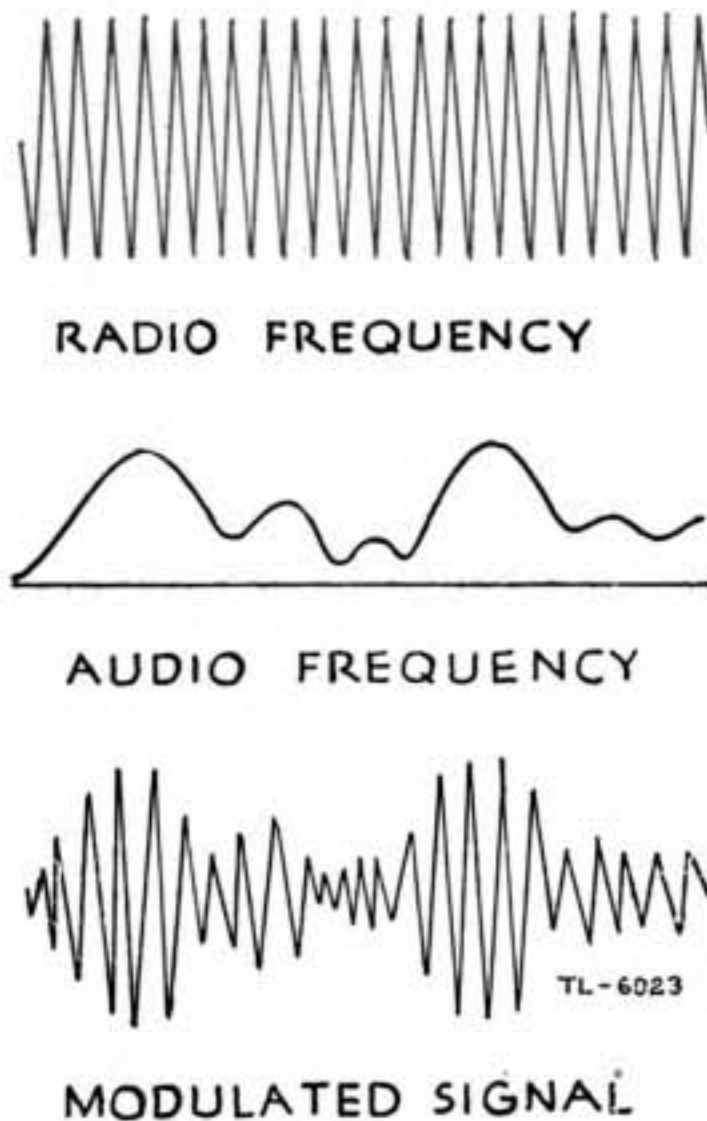


Figure 82. Formation of a modulated waveform.

50. Phone Detection

In paragraph 5 it was shown that a radiotelephone or a modulated signal is produced by controlling the r-f output of a transmitter at an a-f rate. The chart in figure 82 shows an r-f voltage, an a-f voltage, and the two of them combined to form a *modulated-signal voltage*. The modulated signal is the waveform of the voltage which will appear in the antenna circuit of a radio receiver when a modulated wave is being received. The detector, then, must separate the a-f voltage from the r-f voltage, so that the a-f voltage can be converted into sound by means of a headset or loudspeaker. The detector must demodulate the signal.

51. Diode as Detector

a. In the study of the diode as a rectifier (par. 35) it was shown that the diode is a conductor when the plate voltage is positive, and that it is a nonconductor when the plate voltage is negative. This property of the diode makes the tube useful for the detection of r-f signals.

b. The action of the diode as a detector can best be explained by an examination of a simple diode radio receiver (fig. 83). In this receiver the modulated r-f signal voltage will appear across the parallel-tuned

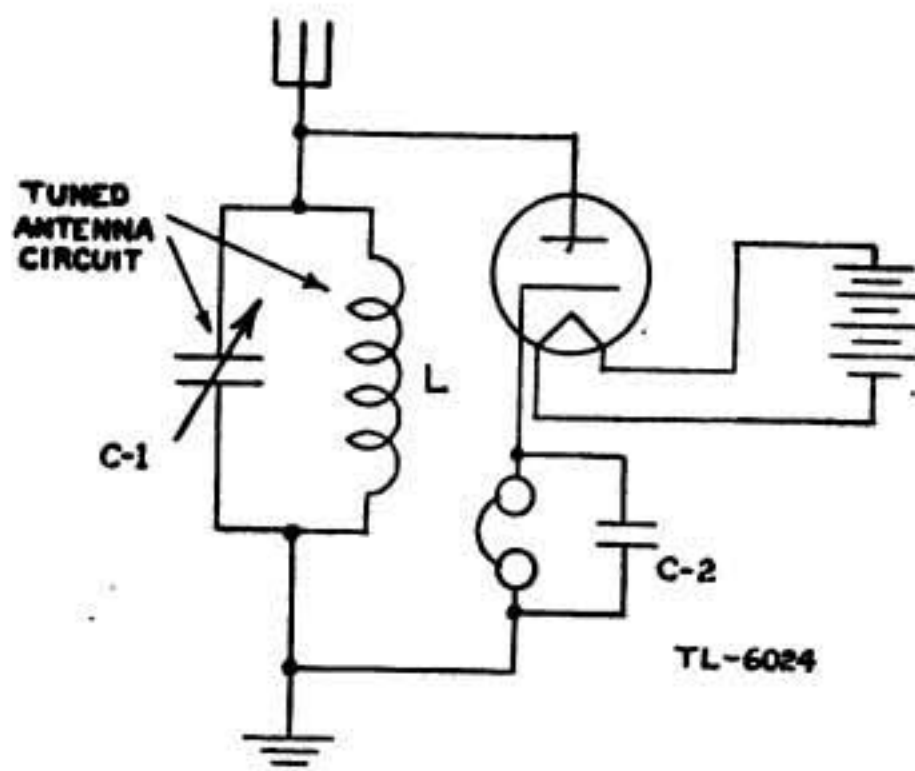


Figure 83. Simple diode radio receiver.

circuit formed by the coil L and the variable capacitor C_1 when this antenna circuit is tuned to resonance with the incoming r-f signal. Since the diode is connected to this antenna circuit, it will rectify the signal voltage, and the rectified-signal current will flow through the headset, thereby producing sound. Obviously, the a-f part, or component, of the voltage which appears across the headset must not be filtered out, as this voltage produces the sound. But the headset will have an extremely high reactance at the frequency of the incoming signal, which would reduce the amount of r-f current flowing in the

circuit. For this reason capacitor C_2 is placed across the headset (fig. 83). The size of this capacitor is chosen so that it will have a low reactance at the radio frequencies, and a relatively high reactance at the audio frequencies, thus providing minimum opposition to r-f current.

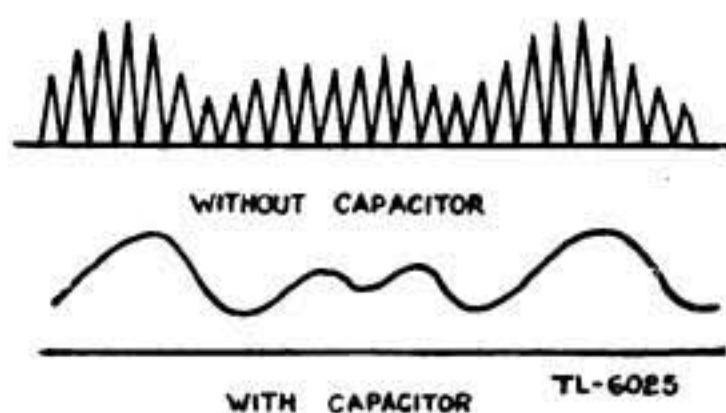


Figure 84. Effect of a bypass capacitor.

flow in the entire circuit, while providing maximum opposition to a-f current flow. Consequently, the maximum a-f voltage appears across the headset. Figure 84 shows this rectified voltage appearing across the headset, both with and without bypass capacitor C_2 connected.

c. The action of the diode as a detector is essentially the same as its action as a rectifier, since the diode actually detects the r-f signal by rectifying it. The circuit shown in figure 83 is the basic detector circuit for many of the radio receivers now in use. However, since the diode does not amplify the signal it is detecting, its use as a detector requires several preceding stages of r-f amplification to bring the level of the signal up to a point of satisfactory output. This is done in modern radio receivers with a large number of tubes. If, however, a radio set is to use a smaller number of tubes, and consequently have fewer stages of amplification, it must have a detector which is more sensitive than the diode; in other words, the detector must *amplify* the signal as well as detect it. The *triode* as a detector fulfills this requirement.

52. Grid-leak Detector

a. The *grid-leak detector* functions like a diode detector followed by a stage of triode amplification. Figure 85 shows only the grid and the cathode of a triode connected as a diode detector; the triode grid acts

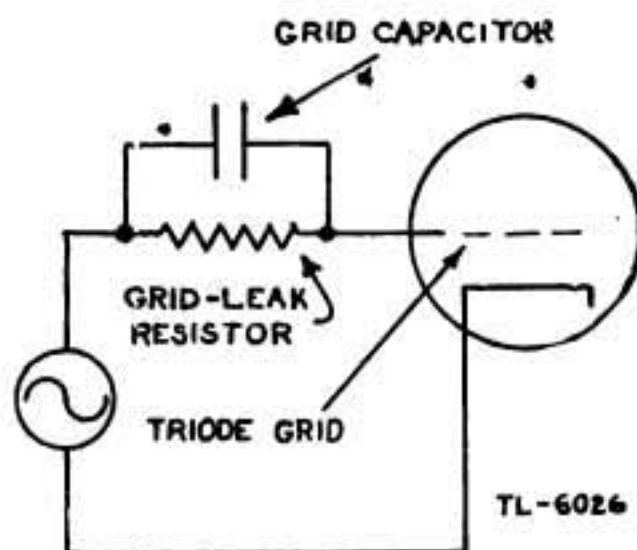


Figure 85. Diode action in a triode.

as the plate of the diode. It can be seen that the grid-leak resistor forms the load for the diode circuit, while the grid capacitor is the r-f bypass, or filter capacitor, in the circuit. When a modulated a-c signal voltage is applied to the circuit of figure 85, current will flow through the tube only on the positive half-cycles, and consequently the signal will be rectified, or detected. Since electrons flow only from the cathode to the "plate" of the diode, the voltage drop across the grid-leak resistor, caused by the current flow on the positive half-cycles, will make the diode "plate" (the triode grid) negative with respect to the cathode. This rectified-signal voltage thus acts as *bias* for the triode grid.

b. Consider next the complete grid-leak detector circuit shown in figure 86. Since the bias for the triode is produced by rectifying the modulated-signal voltage, the bias will increase and decrease in value in proportion to the modulation on the r-f signal (at an a-f rate). In other words, the grid voltage will vary in just the same manner as it did in figure 62, where an a-c voltage was applied to the grid (of a triode) in series with a source of fixed negative grid bias. Since the triode plate current is determined by the grid voltage, the plate current in the circuit shown in figure 86 will vary in proportion to the voltage appearing across the grid-leak resistor. The plate current in this circuit flows through the headset as a load. The voltage drop across

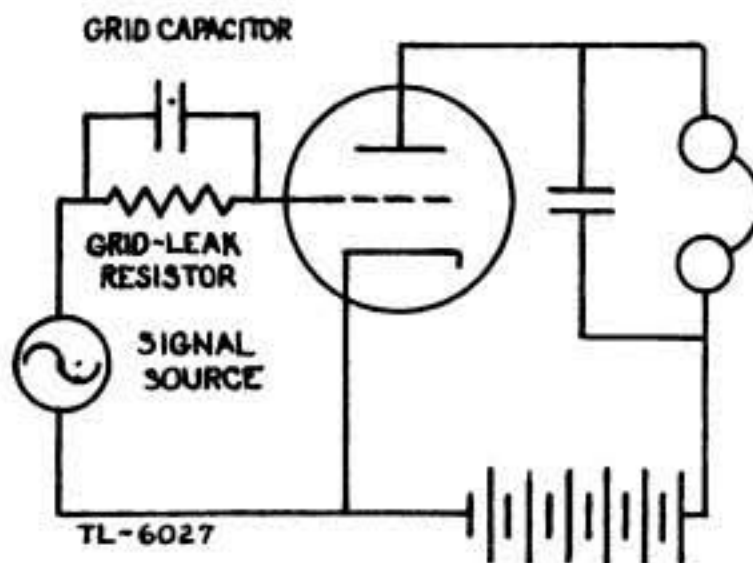


Figure 86. Grid-leak detector circuit.

the headset, produced by the variations in plate-current flow, will therefore be an amplified reproduction of the voltage appearing across the grid-leak resistor. The capacitor connected across the headset in figure 86 bypasses any r-f voltage (amplified by the tube) around the headset. Since the plate current in a circuit decreases as the grid is made more negative, the average plate current of the grid-leak detector circuit will decrease as the applied signal voltage becomes greater. The maximum plate-current flow will occur in this circuit when no signal is being received, because at that time there is no bias voltage developed by the grid leak. Since the actual detection of the signal in the grid-leak detector takes place in the grid circuit, this type of detector is also known as a *grid detector*.

c. The chief disadvantage of the grid-leak detector circuit is that it is easily overloaded by strong r-f signals with consequent distortion of output. When grid-leak detectors are used to handle large r-f signal voltages, they are called *power detectors*, and are sometimes used in radio receivers which have several stages of r-f amplification preceding the detector stage.

53. Plate Detection

a. When the triode-detector circuit is arranged so that rectification of the r-f signal takes place in the plate circuit of the tube, such a circuit is called *plate detection*. If a sufficient negative grid bias is applied to a triode circuit so that the plate-current flow is cut off when no signal is applied, the proper conditions have been established for plate detection. This cut-off bias may be supplied either by means of a cathode resistor, or by means of a fixed source of bias (fig. 87). If a modulated r-f signal is applied to the circuit of figure 87, plate current

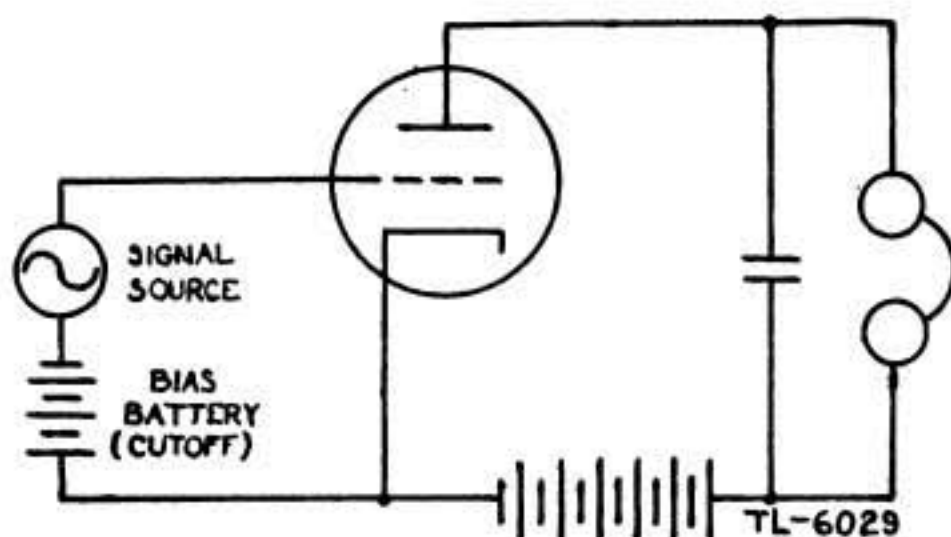


Figure 87. Plate detection.

will flow during the positive half-cycles of the r-f voltage, since the positive voltage will cancel part of the negative bias voltage, thereby reducing the grid voltage below the cut-off point. Plate current will not flow during the negative half-cycles of the r-f voltage, since the negative voltage merely adds to the bias voltage, making the grid more negative. Thus, the tube acts as a plate detector, since plate current flows only during the positive half-cycles of the r-f voltage.

b. The action of the plate detector can be further demonstrated by means of the $E_G - I_P$ curve shown in figure 88. The modulated r-f is applied to the grid-voltage scale of the graph, and the resultant plate-current waveform is developed on the plate-current scale. Since cut-off bias is applied to the plate detector, no plate current will flow when no signal is applied to the circuit. The average value of the plate current will increase as the strength of the applied signal is increased; this effect is opposite to that of the grid-leak detector. In general, the plate detector is less sensitive than the grid-leak detector, but it has the advantage of being less easily overloaded.

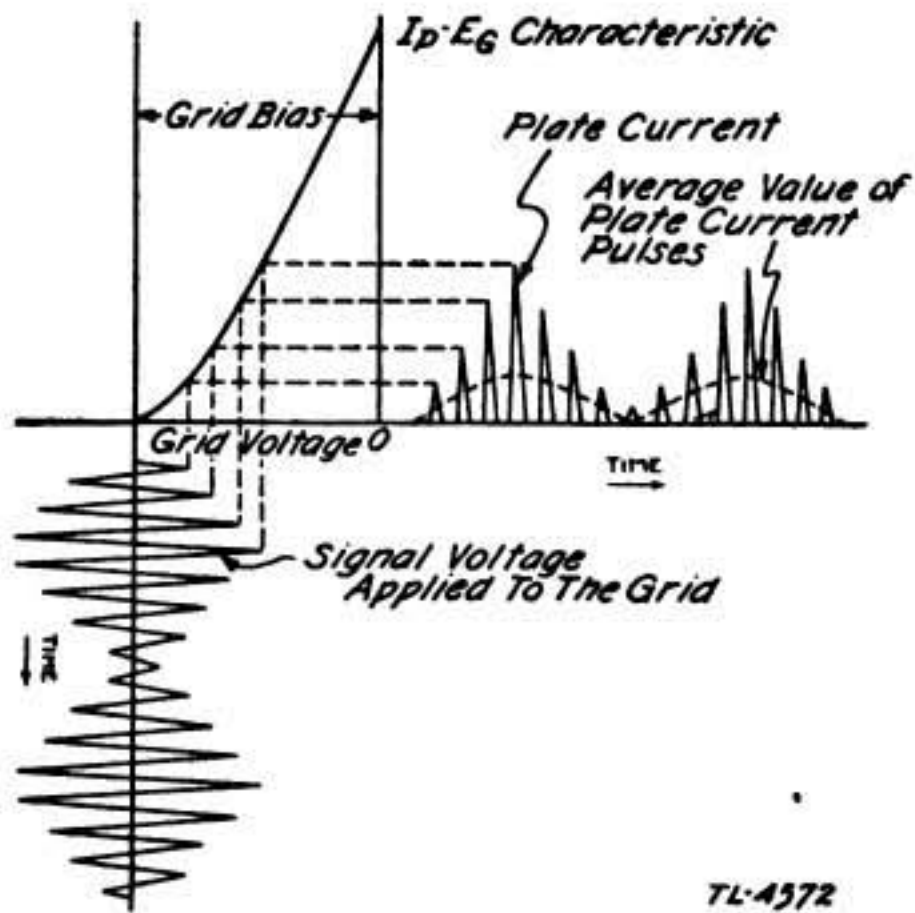


Figure 88. Operating conditions of a plate detector.

54. Regenerative Detection

a. The process of feeding some of the output voltage of a vacuum-tube circuit back into the input circuit, so that it adds to, or reinforces (is in phase with) the input voltage, is known as *regeneration*. The use of regeneration in a circuit greatly increases the amplification of the circuit, since the output voltage fed back into the input circuit adds to the original input voltage, thus increasing the total voltage to be amplified by the tube.

b. Regeneration, sometimes called *positive feedback*, can be applied to a grid-leak detector circuit by connecting a coil in series with the

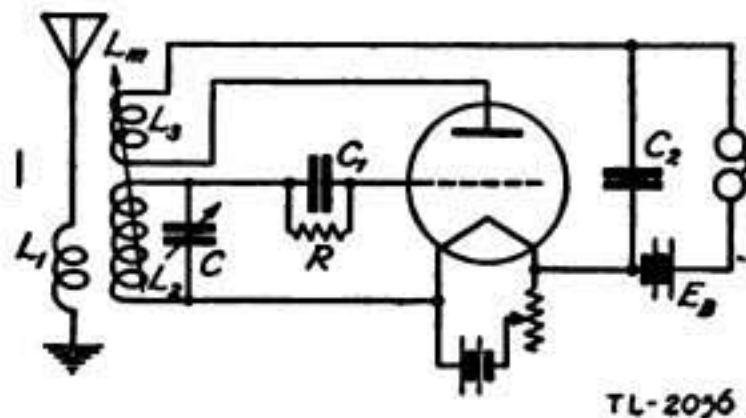


Figure 89. Regenerative detector.

plate circuit and magnetically coupling it to the grid coil (fig. 89). When an r-f signal is applied to the circuit, voltage will be built up across this feedback, or *tickler* coil (L_3 in fig. 89), because of the plate-current variations and the reactance of the coil. Since this tickler coil is magnetically coupled to the grid coil (L_2 on the diagram), transformer action takes place between the two windings and a voltage is set up in the grid coil. Since the tickler coil has been so placed that the voltage it induces into the grid coil will be in phase with the incoming-

signal voltage, the voltage feedback will *add* to the incoming r-f signal voltage and increase the total voltage to be amplified by the tube, thus *increasing the amplification of the circuit*. It is important that the position of the tickler coil with respect to the grid coil be correct, for if it is not and the feedback voltage is out-of-phase with the input voltage, it will cancel some of the input voltage, and thereby reduce the amplification of the circuit. In the circuit diagram of figure 89, the antenna coil L_1 , and the grid coil, L_2 , form an r-f transformer. Since there are more turns on L_2 than on L_1 , the voltage appearing in the antenna circuit will be stepped up by the use of this transformer, thus producing additional gain in the circuit. The secondary of the transformer, L_2 , and variable capacitor, C , form the parallel-tuned circuit of the set. C_2 bypasses any r-f currents in the plate circuit around the headset and the plate battery E_B . As is very often the case in Army sets, the filament is heated by means of a battery. The regenerative-detector circuit of figure 89 is the most sensitive triode-detector circuit possible, and when used as a receiver it is capable of receiving signals over extremely long distances under good conditions.

55. C-w Detection

All detector circuits previously discussed are used to detect *modulated* signals, since they separate the audio frequencies from the radio frequencies. All of these detector circuits will also rectify unmodulated, or continuous-wave (c-w) signals, but no a-f voltage will appear in their output circuits, since there is no a-f voltage component present in an unmodulated signal. In order to receive c-w signals from a radiotelegraph transmitter, it is necessary to have some method of producing an a-f voltage in the detector circuit when an unmodulated r-f signal is being received.

56. Heterodyne Detector

a. If two a-c signals of different frequencies are combined, or mixed, in a circuit, a third signal, called a *beat frequency*, will be produced. The frequency of this beat is equal to the difference between the frequencies which are mixed to produce it. Thus, if two a-f voltages are combined, the frequencies of which are 500 and 600 cycles per second respectively, a beat frequency of 100 cycles will be produced.

b. If two r-f signals are combined, the frequencies of which differ by an audio frequency, a beat frequency of an a-f voltage will be produced. For example, if a 1,000-kilocycle signal is mixed with a 1,001-kilocycle signal, a beat, with a frequency of 1 kilocycle (1,000 cycles, or an audio frequency), will be produced. If some way can be found of generating a signal in a detector circuit, the frequency of which differs from the frequency of the incoming signal by an audio-frequency amount, then an a-f voltage will be produced in the circuit.

This can be done by making the regenerative-detector circuit oscillate. If the regeneration, or positive feedback, in a regenerative-detector circuit is increased beyond a certain critical point, the circuit will oscillate, or produce an alternating current, the frequency of which is equal to the resonant frequency of its tuned circuits. Thus, by making the regenerative detector an oscillating detector, and tuning it so that the frequency it generates will differ from the incoming r-f signal frequency by an audible amount, it is possible to detect unmodulated r-f signals. This process is known as "heterodyning," and an oscillating detector is called a *heterodyne detector*. The heterodyne principle is used in radio receivers whenever c-w reception is desired. It is also the basis for most of the oscillator circuits used in transmitters and receivers.

57. Vacuum-tube Voltmeter

a. The plate-detector circuit, discussed in paragraph 53, is used as the basis for a very important measuring device in radio: the *vacuum-tube voltmeter*. A circuit diagram of the vacuum-tube voltmeter is shown in figure 90, and its similarity to the plate-detector circuit will

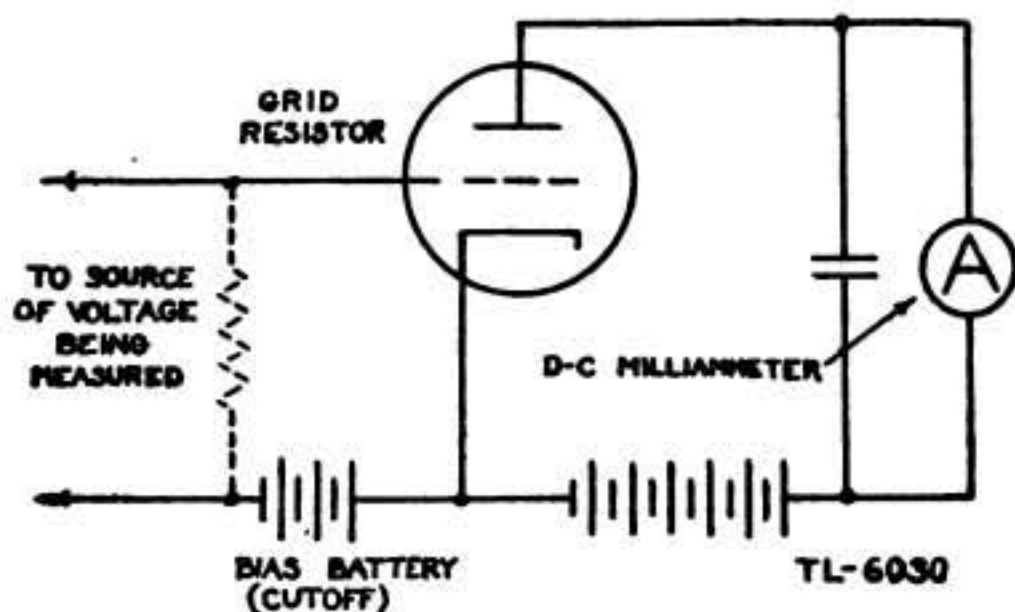


Figure 90. Vacuum-tube voltmeter.

be obvious. When no voltage is applied to the grid of this circuit, no plate current will flow, since the grid is biased to cut-off. If an a-c voltage is applied to the grid, however, plate current proportional to the peak (or highest value of the applied voltage) will flow, and operate the milliammeter (which replaces the headset of the plate-detector circuit). If a d-c voltage is applied, the plate current indicated by the milliammeter will be proportional to the applied voltage, provided that the positive terminal of the voltage being measured is connected to the grid, and the negative terminal is connected to the bias battery.

b. By calibrating the milliammeter so that it reads either a-c volts or d-c volts, or both, the circuit becomes an effective voltage-measuring device. The advantage of the vacuum-tube voltmeter is that it draws little or no current from the source of voltage being measured. This is in contrast to conventional meters, and thus gives far more accurate results when critical measurements are being made.

SECTION VI

VACUUM-TUBE AMPLIFIERS

58. Voltage and Power Amplifiers

a. The basic manner in which a signal can be amplified by a vacuum tube (par. 37) can be applied to vacuum-tube amplifiers which fulfill various special requirements of transmitters and receivers. The importance of amplifier circuits can be seen from their wide variety of uses in radio work.

(1) In transmitters, the r-f power generated by the oscillator is too small for satisfactory long-distance transmission; therefore, *r-f power-amplifier* stages are used to increase this power to the desired level before transmitting.

(2) The a-f voltage output of a microphone is too small to operate the modulator stage of a radiotelephone transmitter; therefore, *a-f voltage-amplifier* stages are used to increase the output of the microphone to the amount required for proper operation of the modulator.

(3) *R-f voltage-amplifier* circuits are used in receivers to increase the strength of weak signals, so that satisfactory detector operation may be realized.

(4) A-f voltage-amplifier stages are also used in receiver to amplify the a-f output of the detector stage for greater headset volume.

(5) If loudspeaker operation is required in a set, the output a-f amplifier stage will be an *a-f power amplifier*.

b. From this discussion of amplifier circuits, it may be concluded that a vacuum-tube amplifier stage, either r-f or a-f, can be classified as a voltage amplifier or a power amplifier, according to the purpose for which it is to be used.

c. *Voltage amplifiers* are amplifier stages designed to produce a large value of amplified-signal voltage across a load in the plate circuit. In order to produce the largest possible value of amplified-signal voltage across the load of such a circuit, the opposition of the load to plate-current change (that is, its resistance, reactance, or impedance) must be as high as is practically possible.

d. *Power amplifiers* are amplifier stages designed to deliver a large amount of power to the load in the plate circuit. In a power amplifier, not only must there be a large output voltage across the load, but there must also be current flowing through the load, since power equals voltage times current.

is not linear over its entire length, that is, it is not a straight line. In order to produce a plate-current waveform which, as nearly as possible, is an exact reproduction of the signal-voltage waveform, the tube must be biased so that it will operate on that portion of its $E_G - I_P$ curve (fig. 91) which is a straight line.

b. If the grid of the tube is biased incorrectly, so that the grid voltage varies over a nonlinear portion of the curve, a distorted plate-current waveform will result (fig. 92). Since the plate current varia-

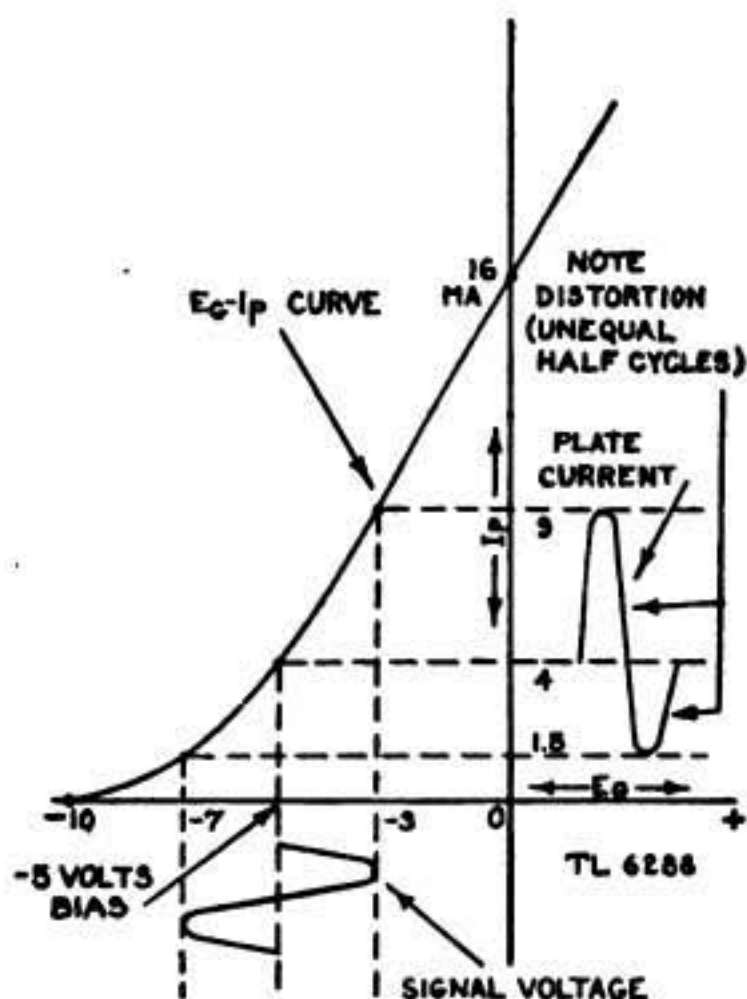


Figure 92. Distortion in a class A amplifier due to improper bias.

tions flowing through the load produce the output voltage in an amplifier circuit, a distorted plate-current waveform will produce a distorted output voltage. It is important, therefore, that the bias voltage be kept at the proper value in class A amplifier stages, in order to avoid distortion.

c. Distortion will also occur in a class A amplifier if too great a value of a-c signal voltage is applied to the grid of the tube, and the total grid voltage (the bias voltage plus or minus the signal voltage) will vary over both linear and nonlinear portions of the $E_G - I_P$ curve (fig. 93).

d. The maximum power output which can be obtained from any amplifier stage will depend on the efficiency of the circuit and the permissible plate-dissipation rating of the particular plate used. The efficiency of an amplifier stage is the ratio of the power output (the power of the signal frequency available at the load) to the plate-power input (the d-c plate voltage times plate current), expressed in percent. For example, if the plate-power input to an amplifier stage is 40

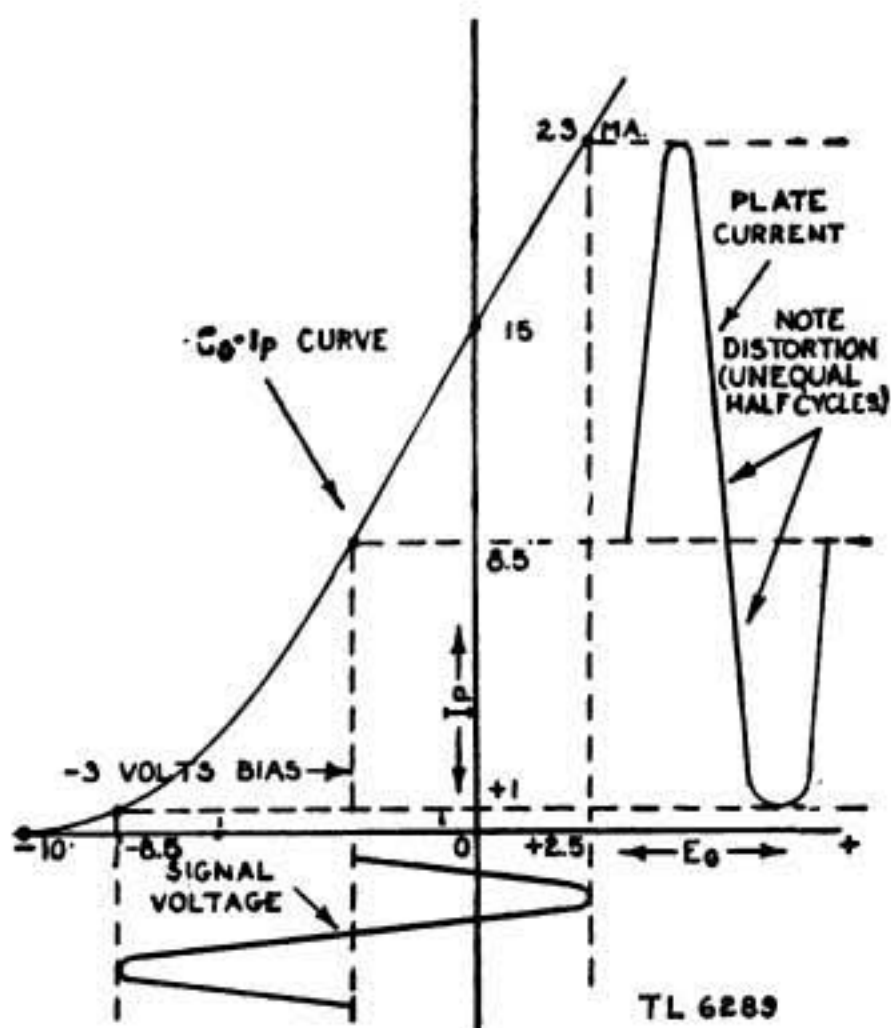


Figure 93. Distortion in a class A amplifier due to excessive signal voltage.

watts, and the power output of the stage is 10 watts, the efficiency of the amplifier stage is 25 percent. The plate dissipation or the power consumed by the plate circuit, of an amplifier stage is the difference between the power input and the power output. Thus, in the example above, the plate dissipation would be the difference between 40 watts and 10 watts, or 30 watts. Each type of tube is rated by the manufacturer as to its maximum safe plate dissipation; this value cannot be exceeded without damaging the tube. The efficiency of class A amplifier stages generally is about 20 to 25 percent.

e. Practically all the amplifier stages of radio receivers, both r-f and a-f are class A operated. Also, the speech-amplifier stages of radiotelephone transmitters (audio stages used to amplify the a-f output of the microphone to the proper signal-input level for the modulator) are class A amplifiers.

60. Class B Amplification

a. If the grid of an amplifier tube is biased at cut-off, so that plate current will flow only during the positive half-cycles of the applied a-c signal voltage, the circuit is called a *class B amplifier*. The $E_G - I_P$ curve in figure 94 demonstrates the relation between grid voltage and plate current in a tube, operated class B. From figure 94, it can be seen that plate current flows only during the positive half-cycles of the a-c signal voltage applied to the grid, and consequently the plate-current waveform is not a replica of the signal-voltage waveform.

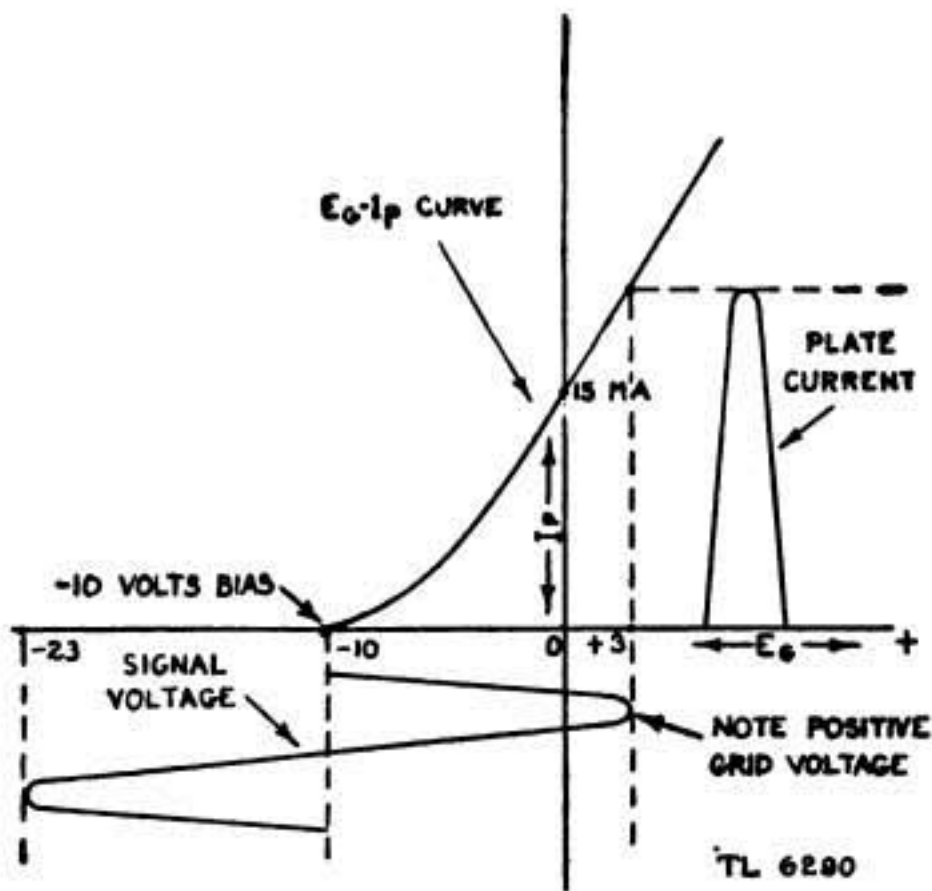


Figure 94. Class B operation.

b. The signal voltage applied to the grid of a class B amplifier is usually much greater in value than that applied to the grid of a class A stage. In fact, the applied signal voltage may be so large that, during part of the positive half-cycles, the grid is actually operated at a positive voltage with respect to the cathode (fig. 94). Since the grid is positive with respect to the cathode during the positive peaks of the applied signal voltage, some of the electrons will be attracted to the grid, and therefore grid current will flow.

c. In order to avoid the large amount of distortion present in the output of a single-tube, or single-ended, class B amplifier stage, two tubes can be arranged in a push-pull amplifier circuit. (See fig. 95.) One tube will operate during the first half-cycle of the a-c signal voltage, and the other tube will operate during the second half-cycle. The action of the push-pull grid circuit in figure 95 is similar to that of the full-wave rectifier circuit. Since plate current flows during one half-cycle in one tube, and during the next half-cycle in the other,

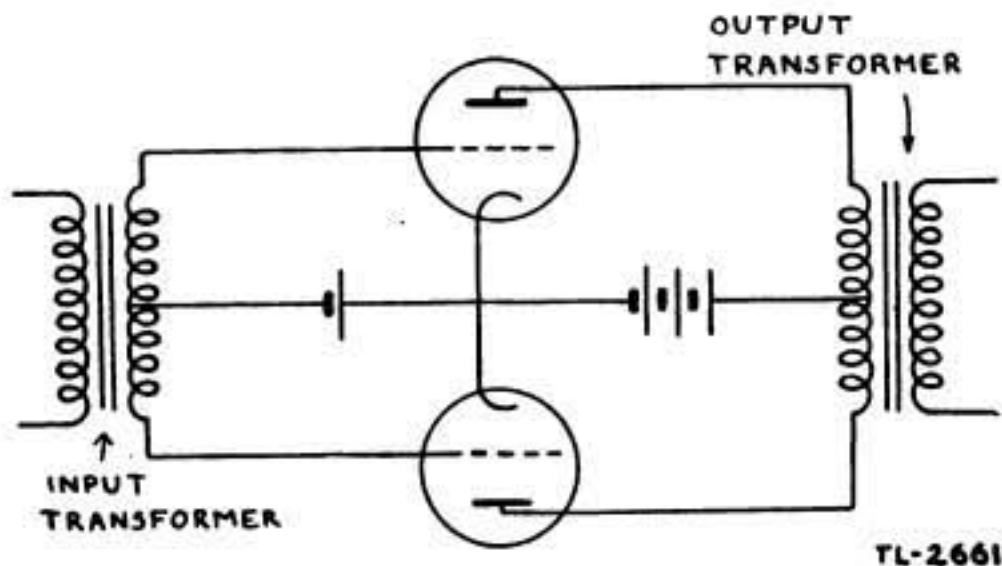


Figure 95. Push-pull amplifier circuit.

the plate current waveforms of the two tubes can be combined in the load circuit. The load circuit in figure 95 is the center-tapped primary of a push-pull output transformer. Since the plate currents of these two tubes flow in opposite directions through their respective halves of the transformer winding, one tube will generate a voltage across the transformer primary during one half-cycle. During the next half-cycle, the other tube will generate a voltage of opposite polarity across the winding. Figure 96 shows the voltage developed across the trans-

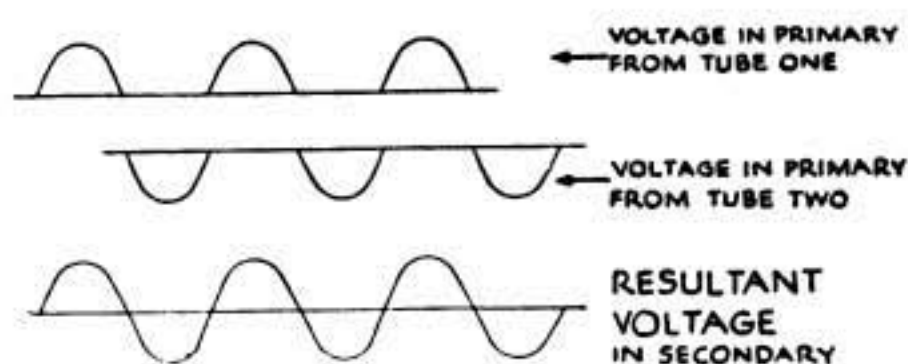


Figure 96. Output of a push-pull class B amplifier.

former primary winding by each tube and the resultant voltage across the transformer secondary, due to combining the voltages over the complete signal voltage cycle. Thus, by using two tubes in push-pull, it is possible to obtain a reasonable undistorted output voltage from a class B amplifier.

d. Class B amplifiers have an efficiency of about 50 to 60 percent, which means a reduced value of plate dissipation and an increased power output for a given power input. They are generally used where it is desired to develop a relatively large power output in the load circuit. Single-tube class B amplifiers are never used for a-f amplification, because of the distorted output of a single tube. Push-pull, class B, a-f amplifier circuits are, however, widely used in the modulator stages of radiotelephone transmitters. They are also occasionally used in the power-output stages of radio receivers.

e. Although the single-ended, or single-tube, class B amplifier is never used in a-f amplifier circuits, it can be used successfully in r-f amplifier stages having a parallel-tuned circuit as the plate load. The parallel-tuned circuit is sometimes called a *tank circuit*, because it has the ability to store power. When it is used as the plate load of a single-ended, class B amplifier stage, the capacitor in the parallel-tuned circuit will be charged by the output voltage produced by the flow of plate current through the load on the positive half-cycles. Although no current flows through the tube on the negative half-cycles of the applied signal voltage, the capacitor will discharge into the inductor during this period, and thus supply the missing half-cycle in the output voltage. This so-called flywheel effect of the tank circuit will occur only when the resonant frequency of the parallel-tuned

circuit is equal to the frequency of the applied signal voltage. Both single-ended and push-pull class B r-f amplifiers are used in the r-f stages of radio transmitters.

61. Class AB Amplification

a. It is possible to compromise between the *fidelity* (low distortion) of class A amplification and the relatively high efficiency of class B operation by biasing the amplifier circuit so that it will operate part way between class A and class B. This is known as class AB amplification.

b. In biasing a tube part way between class A and class B, the tube will not operate over the entire linear portion of its $E_G - I_P$ curve, and therefore some distortion will be present in the output. For this reason, push-pull amplifier circuits are generally used for class AB r-f amplifiers. Because class AB amplification is less efficient than either class B or class C amplification, it is seldom used in r-f amplifier circuits.

c. If the a-c signal voltage applied to a class AB amplifier is kept below the point where grid current flows, the resultant operation is called *class AB₁ amplification*. If the applied signal voltage is great enough to cause grid current to flow during the positive peaks of the signal voltage cycle, the resultant operation is called *class AB₂ amplification*.

62. Class C Amplification

a. If the bias applied to the grid of an amplifier stage is appreciably greater than the cut-off value, the amplification is called *class C*. The operation of such a tube is shown by the $E_G - I_P$ curve in figure 97. Note that in this case the bias voltage is 20 volts, or twice the cut-off

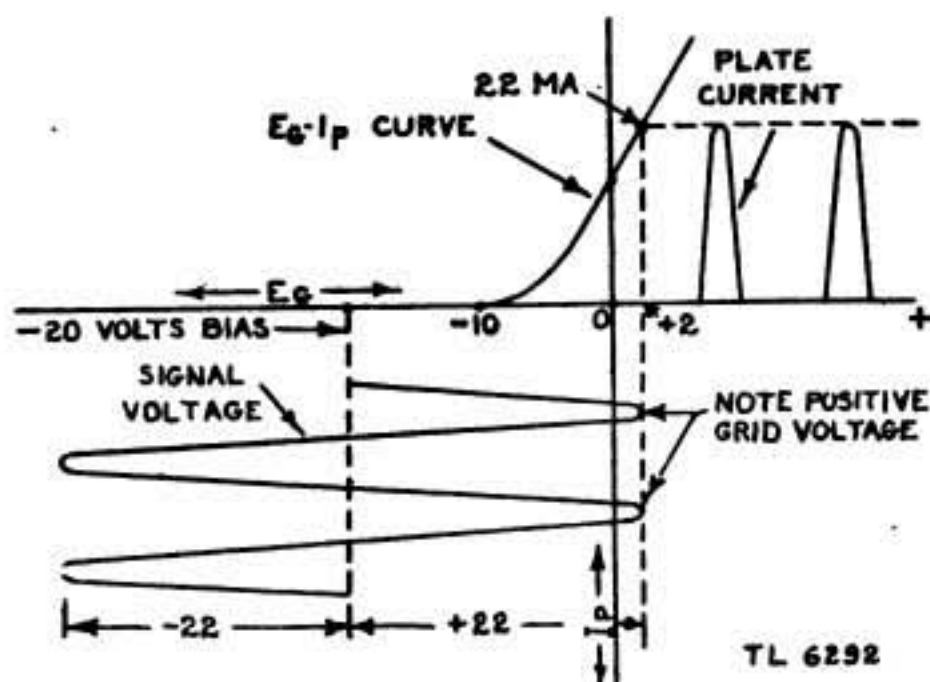


Figure 97. Class C operation.

value; the use of twice the cut-off bias is common practice in many class C amplifiers. The curve shows that plate current will flow only

during that portion of the positive half-cycle of the applied a-c signal voltage, which is numerically greater than the cut-off bias for the tube; that is, plate current flows only during the positive peaks of the applied signal voltage. The curve also shows that the applied a-c signal voltage must greatly exceed the cut-off bias in order to produce a large value of plate-current flow.

b. Almost all of the r-f amplifier circuits used in radio transmitters are operated class C. The parallel-tuned circuits used as plate loads for class C amplifiers exhibit the same flywheel effect as for class B amplifiers. The advantage of class C operation is that it has a high efficiency; efficiencies as high as 75 percent are not uncommon in class C r-f amplifiers. Class C operation is never used in a-f amplifiers because of the high degree of distortion in these circuits.

63. Interstage Coupling

a. Any of the coupling methods, described in paragraphs 27 to 30, may be used to couple the output circuit of one amplifier stage to the input circuit of the next stage. Three types of interstage coupling are shown in the circuit of figure 98. In this circuit, the elements Z_1 are the plate loads for their respective tubes, cathode bias (R_c) is used

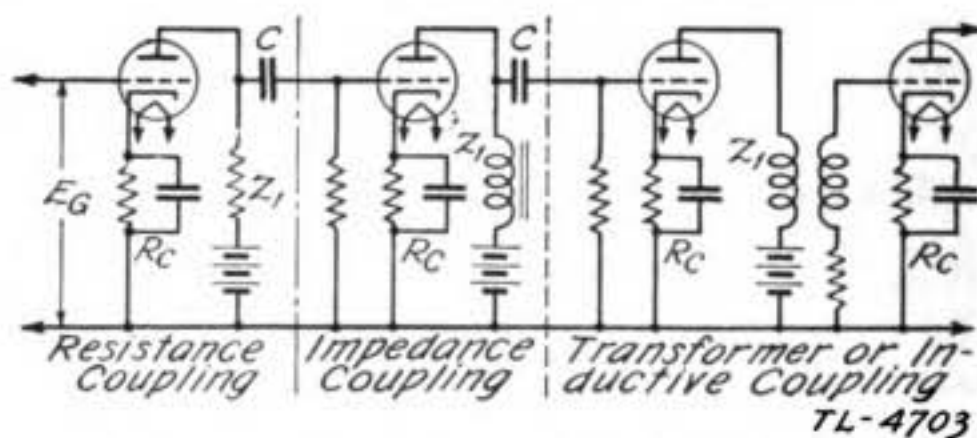


Figure 98. Three types of interstage coupling.

for all four tubes, and the input a-c signal voltage is indicated by E_G . All three of these forms of interstage coupling are widely used in the a-f circuits of both transmitters and receivers. The most common form of coupling found in the r-f amplifier circuits of receivers is transformer coupling, while in the r-f circuits of transmitters, both impedance and transformer coupling are widely used.

b. The first stage of the circuit in figure 98 is resistance-coupled to the second stage, since the amplified-signal voltage is developed across a resistor in the plate circuit. This signal voltage is applied to the grid of the second stage through the blocking capacitor (sometimes called a coupling capacitor), indicated as capacitor C on the drawing. The resistor in the grid circuit of the second stage provides a d-c path for the bias applied to the grid. Since the blocking capacitor plays an important part in the operation of this circuit, this type of coupling is sometimes called *resistance-capacitance coupling*. As the

blocking capacitor will pass alternating current, it applies the amplified-signal voltage developed across resistor Z_1 to the grid circuit of the next stage. At the same time it blocks the flow of direct current from the plate circuit of the first stage to the grid circuit of the second. If this capacitor should break down or develop leakage, some or all of the positive d-c voltage applied to the plate of the first stage would appear on the grid of the second, canceling some or all of the negative bias applied to this tube, and thus causing distortion in its output. A leaky blocking capacitor, therefore, can be a source of distortion in an amplifier circuit.

c. The coupling between the plate circuit of the second tube and the grid circuit of the third tube (fig. 98) is similar in operation to the coupling between the first and second tubes, except that an inductor having a high value of reactance at the signal frequency is used as a plate load. The function of the blocking capacitor is the same for both resistance and impedance, or inductance, coupling.

d. A transformer is used to couple the output of the third tube to the input of the fourth in the circuit of figure 98. The primary of this transformer is the plate load for the third tube, while the signal voltage applied to the grid of the fourth tube is developed across the secondary of this transformer. If the transformer has more turns on the secondary than on the primary, the signal voltage applied to the grid of the fourth tube will be proportionately greater than the signal voltage developed across its primary. Thus, some voltage amplification is obtained by the use of transformer coupling in amplifier circuits.

e. In general, the only difference between the coupling methods used in a-f amplifier circuits and those used in r-f amplifier circuits lies in the employment of tuned circuits. The circuit of figure 99 shows a tuned impedance-coupled r-f amplifier circuit; the plate loads for the two

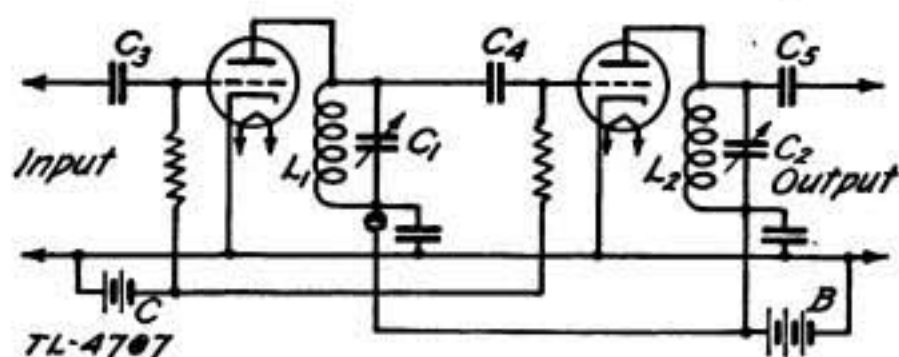


Figure 99. Tuned impedance-coupled r-f amplifier circuit.

tubes are the parallel-tuned circuits formed by L_1 and C_1 , and L_2 and C_2 , respectively. A two-stage, single-tuned, transformer-coupled, r-f amplifier circuit is shown in figure 100; this circuit is typical of those found in most radio receivers. Figure 101 shows the use of double-tuned transformer coupling between two stages of r-f amplification. This circuit has the advantage of providing high selectivity and high gain (amplification) at the frequency to which it is tuned. It should

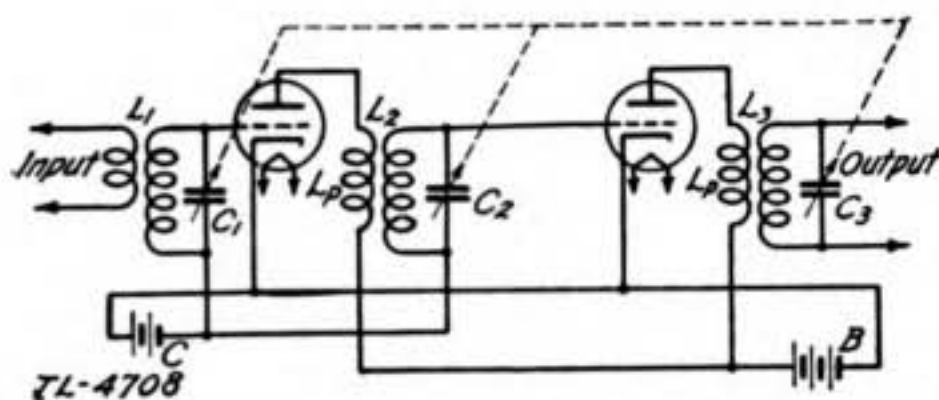


Figure 100. Tuned transformer coupled r-f amplifier circuit.

be noted in the circuits of figures 99, 100, and 101 that batteries common to two stages have been used to provide both negative grid bias and positive plate voltage for the tubes.

f. One of the main considerations in the transformer coupling of a-f power amplifiers is that very little or no distortion should occur. The use of the push-pull circuit greatly reduces distortion in a-f amplifier circuits. For this reason, push-pull is widely used in the a-f power amplifier circuits of radio transmitters and receivers. In class A am-

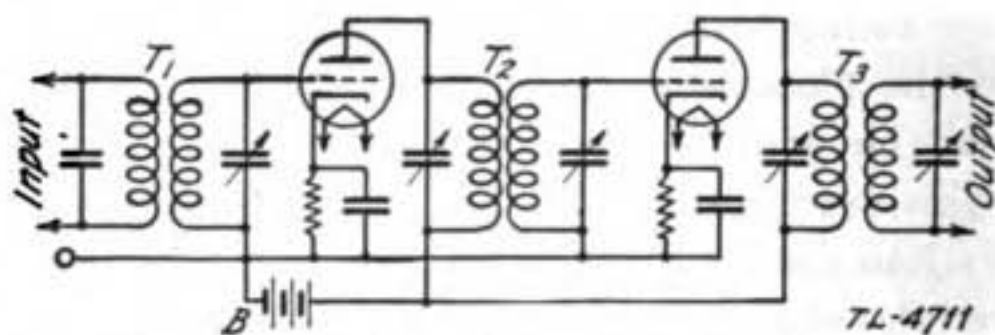


Figure 101. Double-tuned transformer-coupled r-f amplifier circuit.

plifiers, the use of the push-pull circuit permits the application of considerably higher signal voltage per tube for a given amount of distortion in the output than would be possible in single-ended amplifiers. The use of the push-pull circuit is required in classes AB and B a-f amplifiers for low distortion in the output voltage. A center-tapped transformer is the most convenient means of supplying two voltages which are equal to and out of phase with the two grids of a push-pull amplifier circuit from a single-ended stage. Transformer coupling is therefore more widely used than any other method for this purpose.

g. In class AB_2 and class B a-f amplifier circuits, there is another and more important requirement, which necessitates the use of transformer coupling. Most of the tubes intended for use as power amplifiers are so designed that their grids may be operated at a positive voltage in push-pull amplifier circuit without undue distortion. If a positive voltage is applied to its grid, a tube will draw a certain amount of grid current, since some of the electrons will be drawn to the grid. If the grid circuit of a tube drawing grid current contains a large value of d-c resistance, the grid current flowing through this resistance will produce a bias voltage, because of the grid-leak action of the resistance. Since this voltage would be applied to the grid in addition

to whatever value of bias is applied in the circuit, it would change the operating characteristic of the circuit, reduce the power output, and cause distortion. Both class AB_2 and class B a-f amplifier circuits are usually operated so that they will draw grid current when large signal voltages are applied. The d-c resistance of the grid circuit of such amplifiers must, therefore, be kept small in order to prevent the development of undesired additional bias voltages. The low d-c resistance of the windings of a transformer satisfies this requirement. Accordingly, transformer coupling is always used for class AB_2 and class B operation in a-f power amplifier circuits.

h. If the grids of an amplifier stage draw current, they will require a certain amount of power from the signal source. In order to obtain the maximum transfer of power from the plate circuit of the preceding stage, usually called the *driver stage*, the output impedance of this stage must be matched to the input impedance of the push-pull amplifier circuit. This requirement is most conveniently and efficiently met in this type of a-f amplifier by the use of transformer coupling.

64. Gain Control in r-f Amplifiers

a. It was shown earlier (par. 37e) that the gain, or amplification, of a triode may be conveniently controlled by varying the bias voltage applied to its grid. This method of gain control is used more frequently in r-f amplifier circuits than any other method.

b. For *manual control* of the gain of an r-f amplifier, the cathode-bias resistance often is formed by a fixed resistor and a variable resistor connected in series. The fixed resistor is of the correct value to bias the tube for its maximum amplification. The variable resistor may be set at any value from zero to that resistance required for cut-off bias. This provides a convenient method of adjusting the gain of the circuit to any desired value.

c. For *automatic volume control*, additional negative grid bias may be supplied to the r-f amplifier stages of a receiver from the diode-load resistor in the detector circuit. The negative voltage developed across this resistor will be proportional to the signal voltage applied to the detector by the r-f amplifier. The additional negative grid bias applied to the r-f amplifier tubes thus will tend to keep the level of the signal applied to the detector, and consequently the detector output, at a constant value. The circuits and application of automatic volume control are discussed in detail in the sections on radio receivers.

65. Gain Control in a-f Amplifiers

a. The most popular method of volume control for a-f circuits is the use of a potentiometer as the grid resistor of a vacuum-tube amplifier (fig. 102). Since the signal voltage is applied across this variable

resistor, the position of the variable arm of the resistor will determine the value of the signal voltage applied to the grid, and consequently the output of the amplifier.

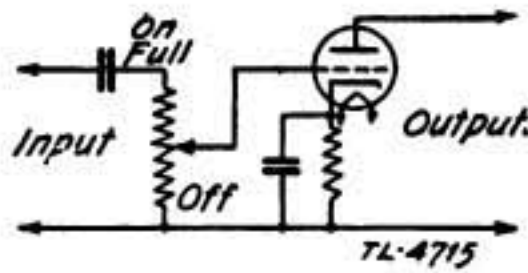


Figure 102. Simple volume-control circuit.

b. Automatic volume control is seldom applied to a-f amplifier circuits, as it is generally more convenient to control the gain of a radio set in the r-f amplifier circuits which precede the detector.

66. Distortion

a. Distortion in an amplifier may be broadly classified under three headings: frequency distortion, nonlinear distortion, and delay (or phase) distortion. Frequency distortion arises because of the inability of an amplifier to amplify all frequencies equally. Nonlinear distortion is a consequence of operating over a curved (nonlinear) portion of a tube's characteristic, so that harmonic or multiple frequencies are introduced. Delay distortion results from the effects of transmission of different frequencies at different speeds, giving a relative phase shift over the frequency spectrum in the output. Except at the ultra-high frequencies or in transmission line work, the effects of delay distortion are usually insignificant. Frequency distortion in r-f transmitter amplifiers is ordinarily of little concern, since these amplifiers operate over only a relatively narrow range of frequencies at any one time.

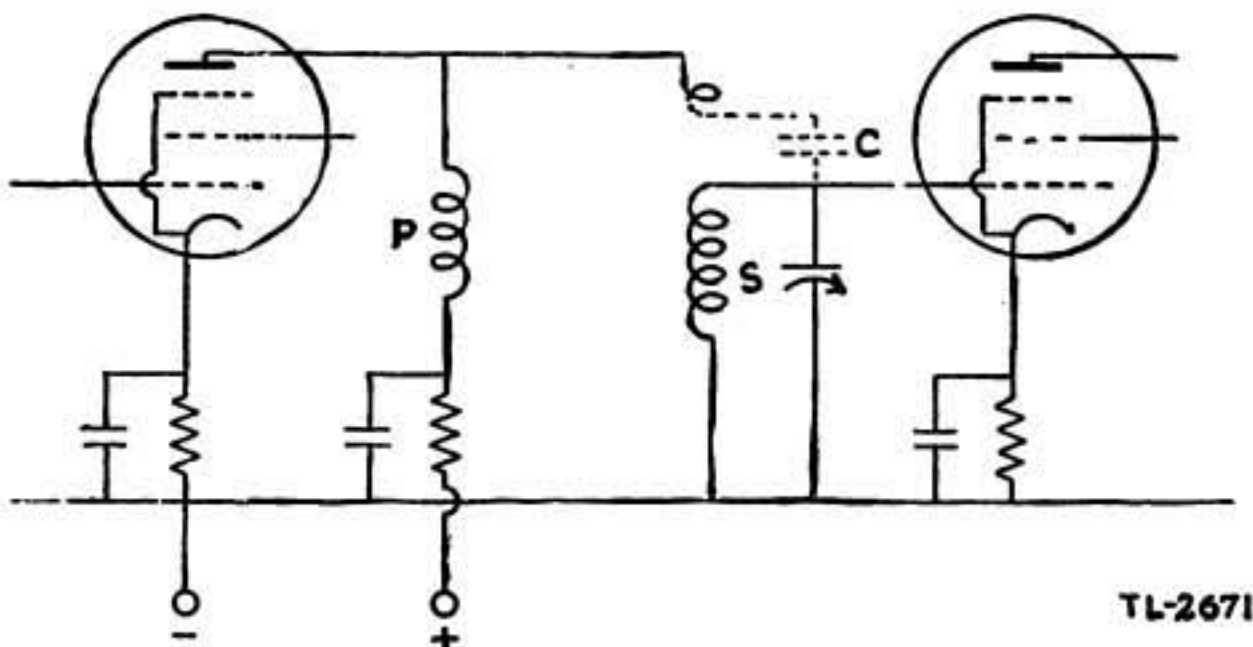


Figure 103. Special circuit arrangement in an r-f amplifier to provide uniform response over a band of frequencies.

b. In r-f receiver amplifiers, various compensating devices are sometimes employed to provide uniform response to a band of frequencies.

Figure 103 illustrates one such compensating arrangement. A high-inductance primary winding P , loosely coupled to the secondary S , resonates (due to self-capacitance) at a lower frequency than the lowest for which the amplifier is to operate. This gives high gain at the low end of the band because of the high plate-load impedance at the lower frequencies. The small capacitance C , due to a loop of wire hooked around the top of the secondary, provides increased coupling at the higher frequencies to improve the response at the upper end of the band.

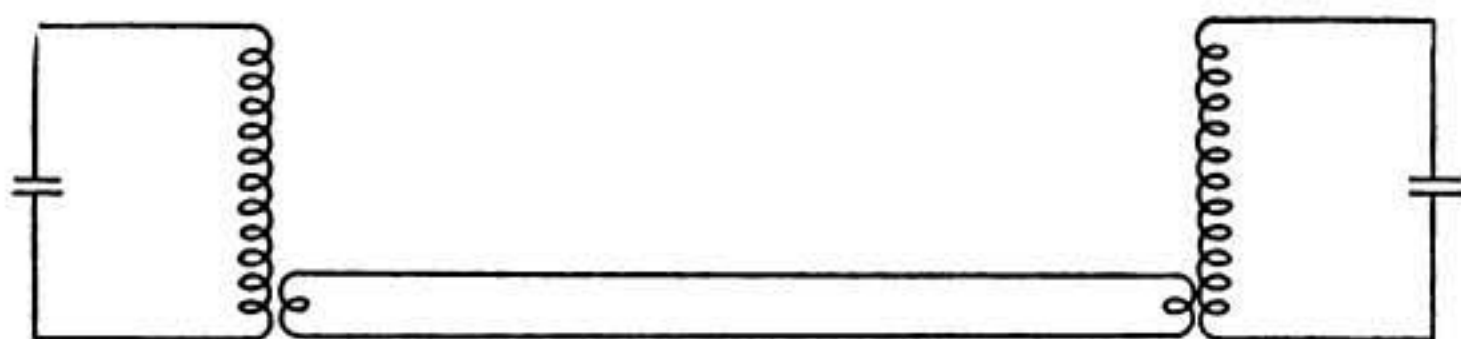
c. Distortion, which arises from operating a vacuum tube over a nonlinear portion of its characteristic, consists principally of multiple frequencies (harmonics) and of sum-and-difference frequencies corresponding to each frequency present in the original signal. Suppose, for instance, that the input signal to a non-linear r-f amplifier is composed of three frequencies: 500,000; 501,000; and 501,025 cycles. The output then contains, in addition to the three original frequencies, the following distortion frequencies:

- (1) Harmonics: 1,000,000; 1,500,000
1,002,000; 1,503,000
1,002,050; 1,503,075
- (2) Sum frequencies: 1,001,000; 1,001,025; 1,002,025.
- (3) Difference frequencies: 1,000; 1,025; 25.

d. The filtering action of a parallel-resonant circuit in an amplifier plate circuit which is tuned to about 500,000 cycles minimizes the effects of all these distortion components. The extent of this suppression of the distortion frequency components may be controlled by proper design of the tuned circuit. At frequencies well off resonance, the parallel circuit offers essentially the impedance of the lowest impedance branch. In a circuit tuned to 500,000 cycles, the impedance offered to currents of 1,000,000 cycles is practically that of the capacitor alone, and the impedance offered to currents of 1,000 cycles is practically that of the inductor alone. Thus a low L to C ratio minimizes the voltages developed across the parallel circuit at the distortion frequencies. Link coupling (fig. 104) is sometimes used to transfer energy between two tuned circuits. This avoids incidental coupling between the two circuits due to the distributed capacitance of the turns and also avoids the transfer of harmonics from one circuit to the other.

e. In an a-f amplifier the distortion frequencies generally overlap components of the desired signal frequencies, so that filtering is not feasible. In a-f amplifiers, the problem demands prevention rather than cure. Class A operation is one solution. Push-pull arrangements are of further assistance.

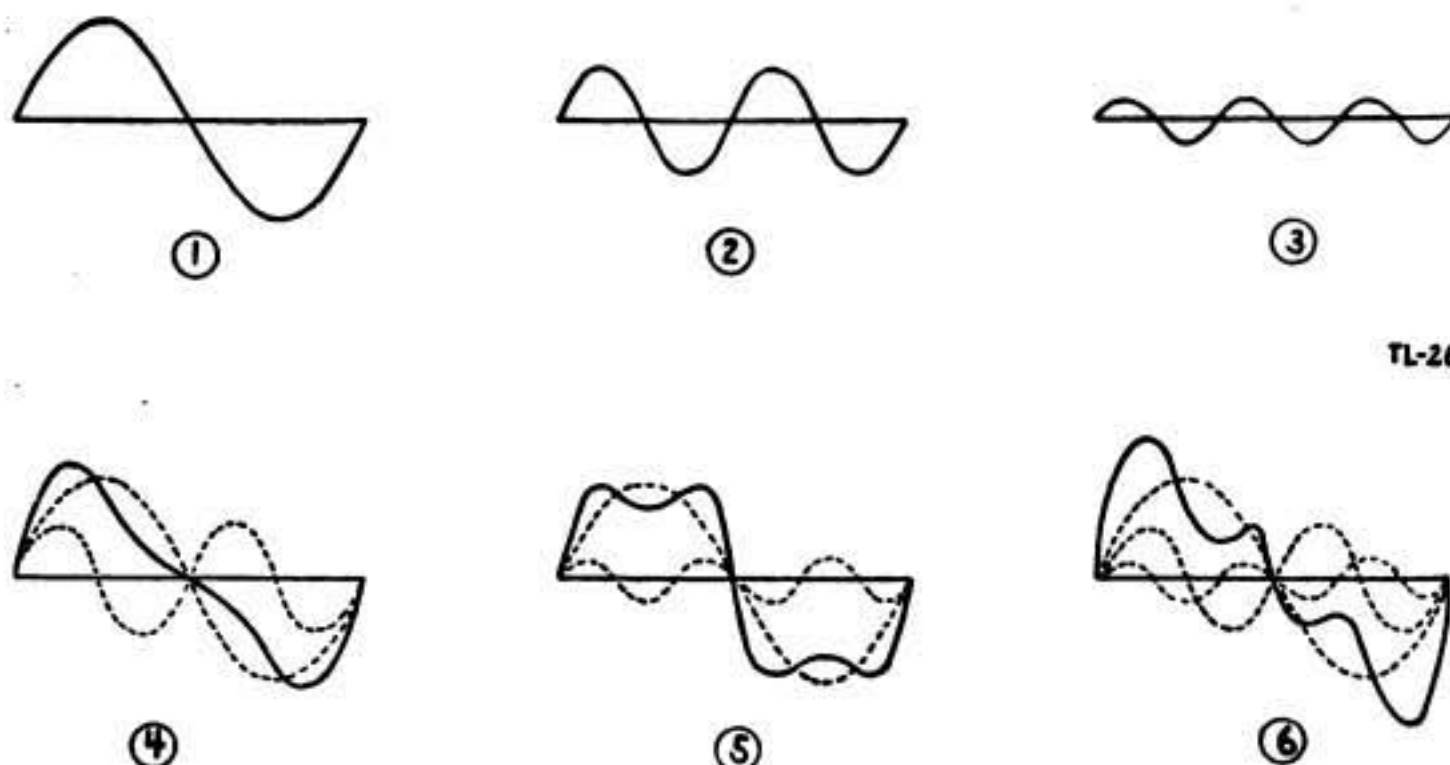
f. Of the harmonic frequencies, the second (first overtone) is usually the predominant one. The rest are ordinarily weak. It is the objection-



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Figure 104. Link-coupled tuned circuits.

able second harmonic (as well as all other even-order harmonics) which is absent in the output of a push-pull amplifier. That this is the case may be seen from a consideration of the curves of figure 105. Here ① represents a fundamental signal frequency (first harmonic); ② and ③ are multiple-frequency curves, second and third harmonics of the signal, respectively. The solid curve of ④ is obtained by adding the fundamental ① and the second harmonic ②. The solid curve of ⑤ is



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- ① *Fundamental.*
- ② *Second harmonic.*
- ③ *Third harmonic.*
- ④ *Fundamental plus second harmonic.*
- ⑤ *Fundamental plus third harmonic.*
- ⑥ *Fundamental plus second and third harmonics.*

Figure 105. Analysis of harmonic distortion.

obtained by adding the fundamental ① and the third harmonic ③. Fundamental, second harmonic, and third harmonic are compounded to yield the solid curve of ⑥. The resultant in ⑤ is such that if the negative half-cycle of the curve is shifted along the abscissa (horizontal axis), so as to be directly below the positive half-cycle, the negative half-cycle then presents a mirror image of the positive half-cycle about the abscissa. It can be shown that any combination of odd-order harmonics possesses this same symmetry; further, that any resultant wave formed by a combination of harmonics and possessing this symmetry

cannot contain any even-order harmonic elements. In push-pull action two tubes interchange roles during alternate half-cycles, so that if the dashed curve of figure 106 represents the output of one tube, the dotted curve of the same figure represents the output of the companion tube. Dissymmetry in the output waveform of each individual tube indicates definite even-order harmonic content, whereas symmetry of the combined waveform shows complete absence of any even-order harmonics.

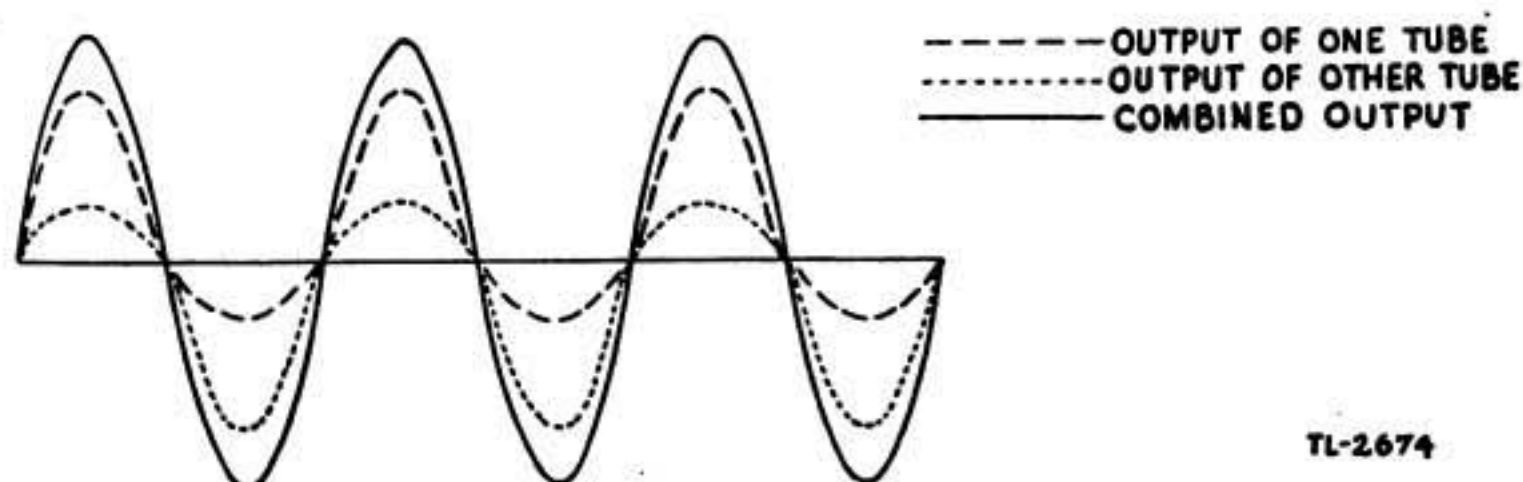


Figure 106. Waveforms in a push-pull amplifier.

g. Push-pull operation serves to lessen distortion in other ways.

(1) The direct currents present in the two halves of the output transformer primary balance each other in their magnetic effects, so that the core cannot become saturated with direct current. (Saturation is a state of magnetization of the core which results from reasonably large currents, so that further increase in current produces only a small increase in magnetic induction.)

(2) Alternating-current components of plate-supply potential, which are due to incomplete filtering, produce no effect in the output transformer secondary, since the potentials thus developed across the primary balance each other. Because of the difficulty of obtaining perfect balance, particularly in tubes, the full possibilities of push-pull amplifiers are seldom realized in practice. However, under conditions of moderately good balance, the push-pull amplifier offers a definite improvement in quality over a comparable single-ended amplifier.

h. For doubling the frequency at radio frequencies in a transmitter, with a single-ended amplifier operating into an appropriately tuned *LC* circuit, harmonic distortion within the tube is deliberately encouraged.

SECTION VII

TUNED RADIO-FREQUENCY RECEIVER

67. Principle of t-r-f Receiver

The *tuned radio-frequency receiver*, or, as it is more commonly called, the *t-r-f receiver*, consists of one or more stages of r-f amplification, a detector stage, and one or more stages of a-f amplification. A block diagram of a typical t-r-f receiver is shown in figure 107. Radio energy waves from a distant transmitter cause a r-f signal current to

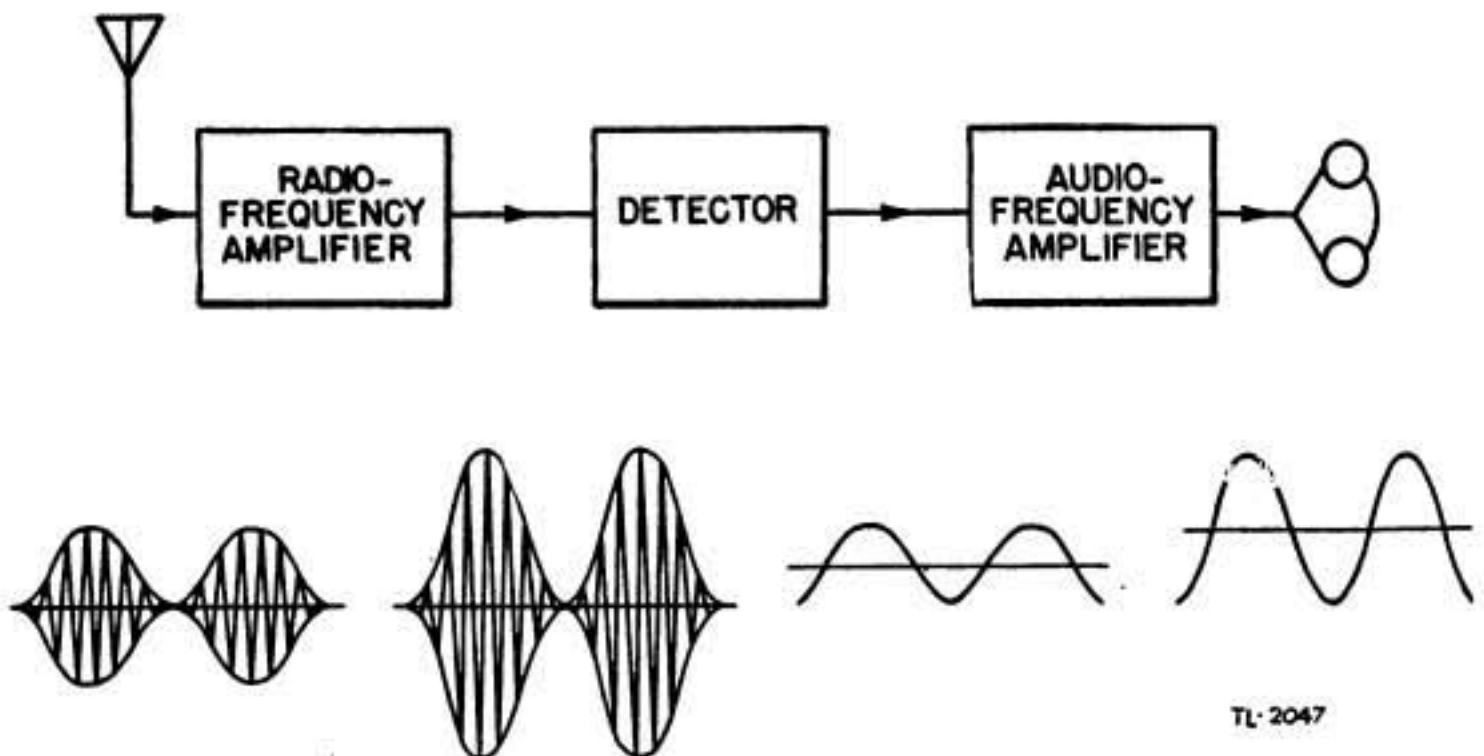


Figure 107. Block diagram of a t-r-f receiver, showing the signal passing through the receiver.

flow in the receiving antenna. This r-f signal is amplified by the r-f amplifier stages, and is then detected, or demodulated, by the detector. The resulting a-f output from the detector stage is amplified by the a-f amplifier stages, and the audible sound is heard in either a loudspeaker or earphones. The waveforms below the block diagram of figure 107 give a comparative indication of this process of converting r-f signals into intelligible a-f signals.

68. R-f Amplifiers

a. Tuned r-f amplifier stages increase the selectivity and the sensitivity of the t-r-f receiver. The more stages that are used the greater will be this increase. Important aspects of the r-f amplifier to be considered are the types of tubes, r-f transformers, capacitors, and

resistors employed, and the nature of band spread and special decoupling circuits.

b. The tubes generally used in r-f amplifiers are tetrodes and pentodes. Any tube suitable for voltage amplification may be used. Triodes, which were used at one time, are not as satisfactory because they have a strong tendency to cause undesirable oscillations in r-f amplifier stages. They also require very careful neutralization (adjustment) to prevent feedback from stage to stage.

c. The basic circuit of a pentode class A t-r-f amplifier is shown in figure 108. The tuned circuit L_1C_1 is coupled to coil L , which in this case is the antenna coil, but could be the plate coil of a preceding stage. Resistor R_1 and capacitor C_2 are the cathode bias resistor and cathode bypass capacitor. Capacitor C_3 is the screen bypass capacitor and R_2

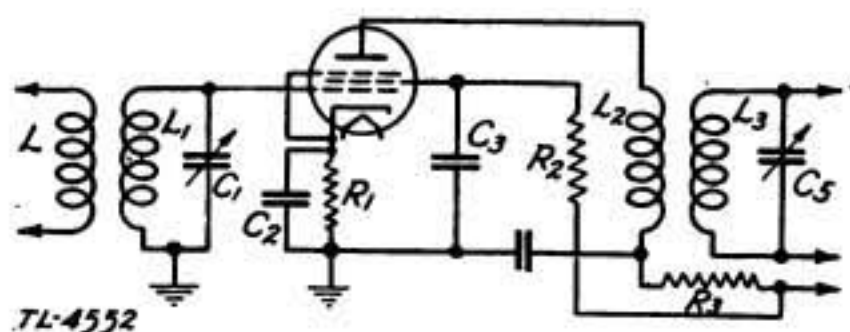


Figure 108. R-f stage of a t-r-f receiver.

is the screen voltage-dropping resistor. A second tuned circuit, L_3C_5 , is coupled to coil L_2 . Coils L and L_1 form the primary and secondary windings, respectively, of an r-f transformer. Coils L_2 and L_3 also form an r-f transformer.

d. The r-f transformer used in most t-r-f receivers consists of a primary coil and a secondary coil. The secondary coil L_1 is designed to cover the desired frequency range when tuned by the tuning capacitor C_1 connected across the secondary. Most r-f transformers in use at the present time are of the air-core type. A few special types may be found which use powdered-iron cores when the frequency of operation is not too high. If a receiver is required to cover a greater frequency range than one coil and tuning capacitor will provide, the tuning circuits of the receiver must be changed to tune to these additional frequency bands. One system is to use plug-in coils, which may be changed to provide the different tuning ranges required. Another system is to mount the various coils for the different frequencies in the receiver, and bring the leads out to a multi-contact rotary switch. This is called *band switching*, and by turning the switch, any desired band can be selected. In both methods the same tuning capacitors are used for all tuning ranges. Both systems of band changing are widely used in Signal Corps receivers.

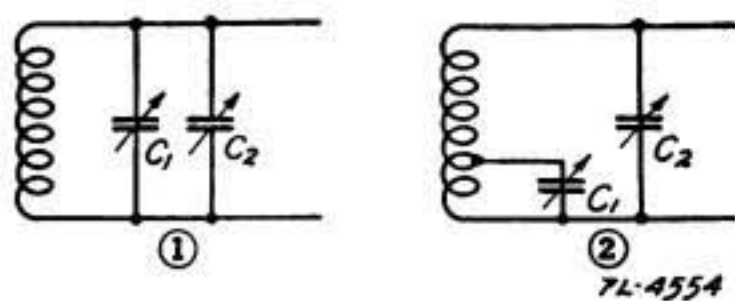
e. Most t-r-f receivers use two or three r-f stages preceding the detector, with each stage tuned to the same frequency. It is therefore more convenient to have all of the tuning capacitors mounted on a

common shaft, so that all stages can be tuned simultaneously. These are called *ganged variable capacitors*. In a receiver having two r-f stages, a three-gang capacitor would be used, with one of its sections tuning each of the three tuned circuits in the receiver. When these tuning circuits are ganged, the coils and the capacitors must be identical. This is necessary in order that all the circuits will tune to the same frequency for any dial setting. Inaccuracies of the coils and capacitors, and stray circuit capacitances will prevent the circuits from tuning to the same frequency. Thus, there must be some method of compensating for these irregularities. This is provided by connecting small trimmer capacitors across each tuning capacitor. These trimmers are adjusted with a screw driver or small wrench, so that each circuit may be tuned exactly to the signal frequency. This process is known as *alignment*. In practice, these capacitors are adjusted at the h-f end of the dial, where the plates of the tuning capacitors are meshed very little and their capacitances are small. The circuits will now be properly adjusted at one dial setting, but they may not tune to identical frequencies at other dial settings. In some sets, this is corrected by slotting the end rotor plates of the tuning capacitors, so that any portion of the end plates may be bent closer to or farther away from the stator plates. When all of the stages tune to identical frequencies at all dial settings they are said to be *tracking*, and maximum gain will be obtained from the receiver. In receivers using band changing, the trimmers for each range are usually mounted on the individual coils. In receivers covering only one band, the trimmers are usually located on the ganged capacitors, one for each section.

f. Resistors used in the r-f amplifier and in the detector circuits are practically all of the small carbon type. The wattage rating will depend upon the voltage drop in the resistor and the current through it.

g. *Band spread* is the process of spreading out a small section of the tuning range of a receiver over the entire scale of a separate tuning dial. The purpose of band spread is to assist in separating stations crowded together in a small space on the main tuning dial. There are two types of band spread: *electrical* and *mechanical*.

(1) In electrical band spread, a small variable capacitor is connected in parallel with the main tuning capacitor in the tuned circuit. The tuning range of the *band-spread capacitor* is only a fraction of the



① *Parallel capacitor band spread.* ② *Tapped-coil band spread.*
 Figure 109. Two types of electrical band spread.

range of the main tuning capacitor. To increase the amount of band spread, the small capacitor may be tapped down on the coil, so that it tunes only a small portion of the coil. Figure 109 shows two methods of electrical band spread.

(2) In mechanical band spread, the band-spread dial is geared to the main tuning dial, so that one complete rotation of the band-spread dial moves the main tuning dial and capacitor over only a fraction of its range.

h. When several amplifier stages are operated from a *common* plate supply, there is a possibility of undesirable oscillations being set up because the plate circuits of the various stages are coupled together by the common impedance of the plate supply. (See fig. 110①.) Note that the plate voltage of both tubes is obtained from a common *B*, or plate, supply. The *internal* resistance of this common supply is represented by *R*. Any change of plate-current flow in tube 2, such as a signal current, will cause a change of voltage across *R*. This causes a

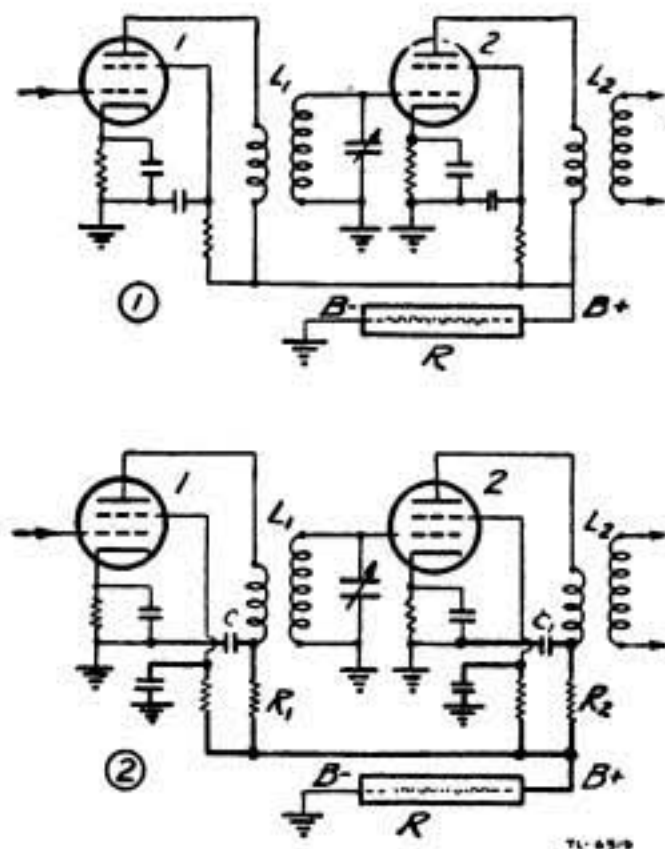


Figure 110. R-f amplifier, without and with decoupling circuit.

change of the *B* supply voltage to the plate of tube 1, and induces a voltage in L_1 , which is connected to the grid circuit of tube 2. This tube will amplify the change and it will appear across L_2 as a larger change. Thus, it can be seen that a part of a signal from the plate of tube 2 is fed back to the grid circuit of the same tube. This condition may cause unwanted oscillations. Circuits to prevent this condition are called *decoupling circuits*, and shown in figure 110②. The capacitors *C* and C_1 , together with resistors R_1 and R_2 , make up the decoupling circuit. The resistors R_1 and R_2 offer a high impedance to the signal voltage, while the capacitors *C* and C_1 bypass the signal voltage around the *B* supply. A choke coil may be used instead of the resistors R_1 and R_2 . The bypass capacitors for the cathode, screen-grid, and plate

circuits in t-r-f receivers are usually paper capacitors, except in circuits intended to operate on extremely high frequencies and in receivers designed for special applications, such as aircraft receivers. In most Signal Corps receivers, the paper capacitors are inclosed in metal cases, two or three capacitors often being grouped together in one can. Where one connection to each capacitor is connected to ground in the circuit, the metal can itself is often the *common-ground* terminal. In some cases, a single terminal may be provided as a common ground for all capacitors in the can.

69. Detector Circuits

Since the voltage amplification of the r-f amplifiers of the modern t-r-f receiver is relatively great, the signal voltage at the input circuit of the detector stage is quite large. As the grid-leak detector is easily overloaded by such large voltages, it is rarely used in present day t-r-f receivers. The two most widely used detector circuits are the diode detector and the power detector.

70. Volume Control

a. Because all signals will not arrive at the receiving antenna with equal intensity, a *gain* or *volume control* is provided so that the volume of the signal received can be varied. This can be accomplished by various means. Those most commonly used are shown in figures 111 and 112.

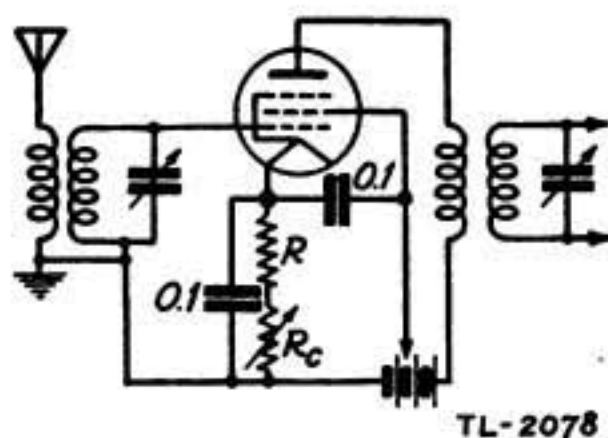
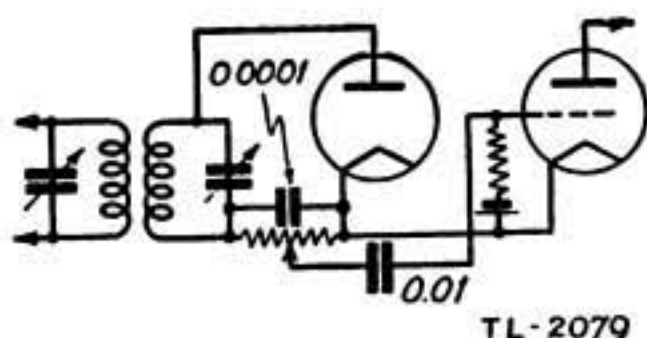


Figure 111. Grid-bias volume control.

In figure 111, the control is in the grid-bias circuit of a variable-mu pentode r-f amplifier. It will be recalled that varying the bias of variable-mu tubes causes the amplification factor to increase or decrease, thus controlling the gain of the stage. The resistor R provides the proper bias for maximum gain when R_c is adjusted to zero resistance. The bias voltages of all r-f amplifier tubes in the receiver are usually controlled when this method is used. Another method, illustrated in figure 112, controls the amount of a-f voltage applied to the grid of the a-f amplifier from the diode detector.

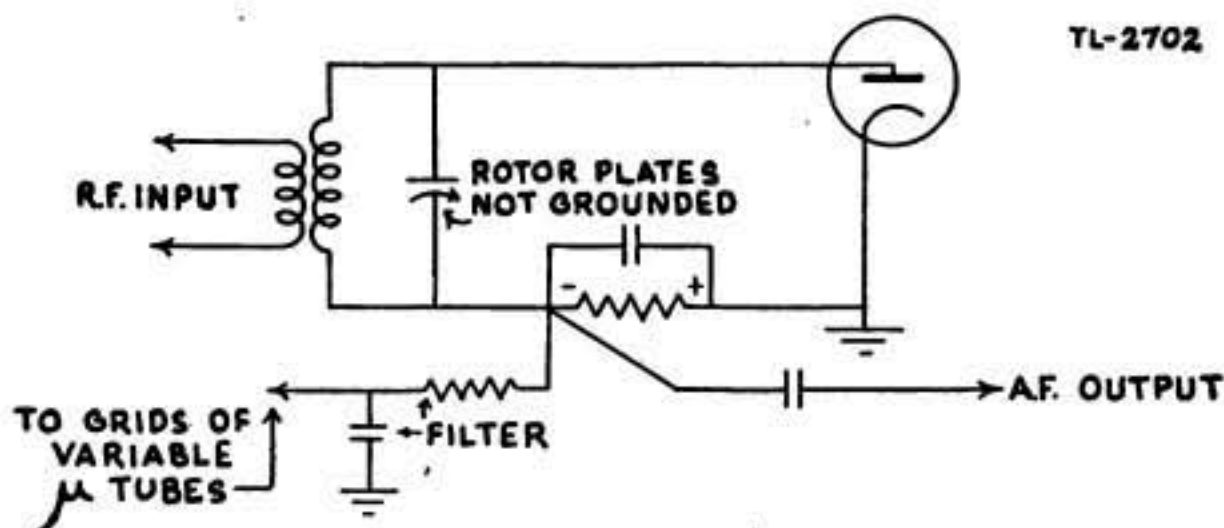
b. Once the volume or gain control of a receiver has been set, the output should remain constant, regardless of the strength of the incom-



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Figure 112. Detector output volume control.

ing signal. The development of the variable-mu pentode tube makes this possible, since the amplification of the tube may be controlled by the grid-bias voltage. All that is needed, then, for *automatic* volume control is a source of voltage which becomes more negative as the signal strength becomes greater. If this voltage is applied as bias to the grids of the variable-mu r-f amplifier stages, the grids will become more negative as the signals grow stronger. This will reduce the amplification, thus tending to keep the output of the receiver at a constant level. The *load resistor* of the diode detector is an excellent source of this voltage, as the rectified signal voltage will increase and decrease with the signal strength. A typical detector diode with an



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Figure 113. Automatic volume-control circuit.

automatic volume control (a-v-c) circuit is shown in figure 113. The signal is rectified by the diode detector, and the rectified current flowing through the load resistor causes a voltage drop across the resistor, as indicated in figure 113. The negative voltage developed is impressed on the grids of the variable-mu tubes in the r-f stages. Any increase in signal strength results in a greater voltage drop and thus is an increase in negative bias to the amplifiers. This results in a decrease in signal strength to the detector. A decrease in signal strength to the detector reduces the amount of negative bias on the amplifier tubes, increases gain in those stages and the input to the detector increases. The filter circuit removes the a-f component of the signal, and only the slower variations due to fading or change in position of the receiver effect the gain of the amplifier stages. Automatic volume control is particularly desirable for mobile receivers in which the signal strength is changeable as the receiver is moved.

c. The variable-mu tube is designed to operate with a minimum bias of about 3 volts. This minimum bias is usually provided by a cathode resistor, and the a-v-c bias is in series with it. A disadvantage of ordinary automatic volume control is that even the weakest signal reduces the amplification slightly. An adaptation which avoids this is shown in figure 114, and is referred to as *delayed* automatic volume control. In this particular circuit the a-v-c diode is *separate* from the detector diode, and both are housed in the same vacuum tube with a pentode amplifier. The tube is called a *duplex-diode pentode*. Part of the energy which is fed to the plate of the detector diode is coupled to the a-v-c diode section by the small capacitor C . The plate of the a-v-c diode is maintained at a negative voltage by means of a cathode-biasing resistor R . This keeps it from rectifying and producing the a-v-c voltage

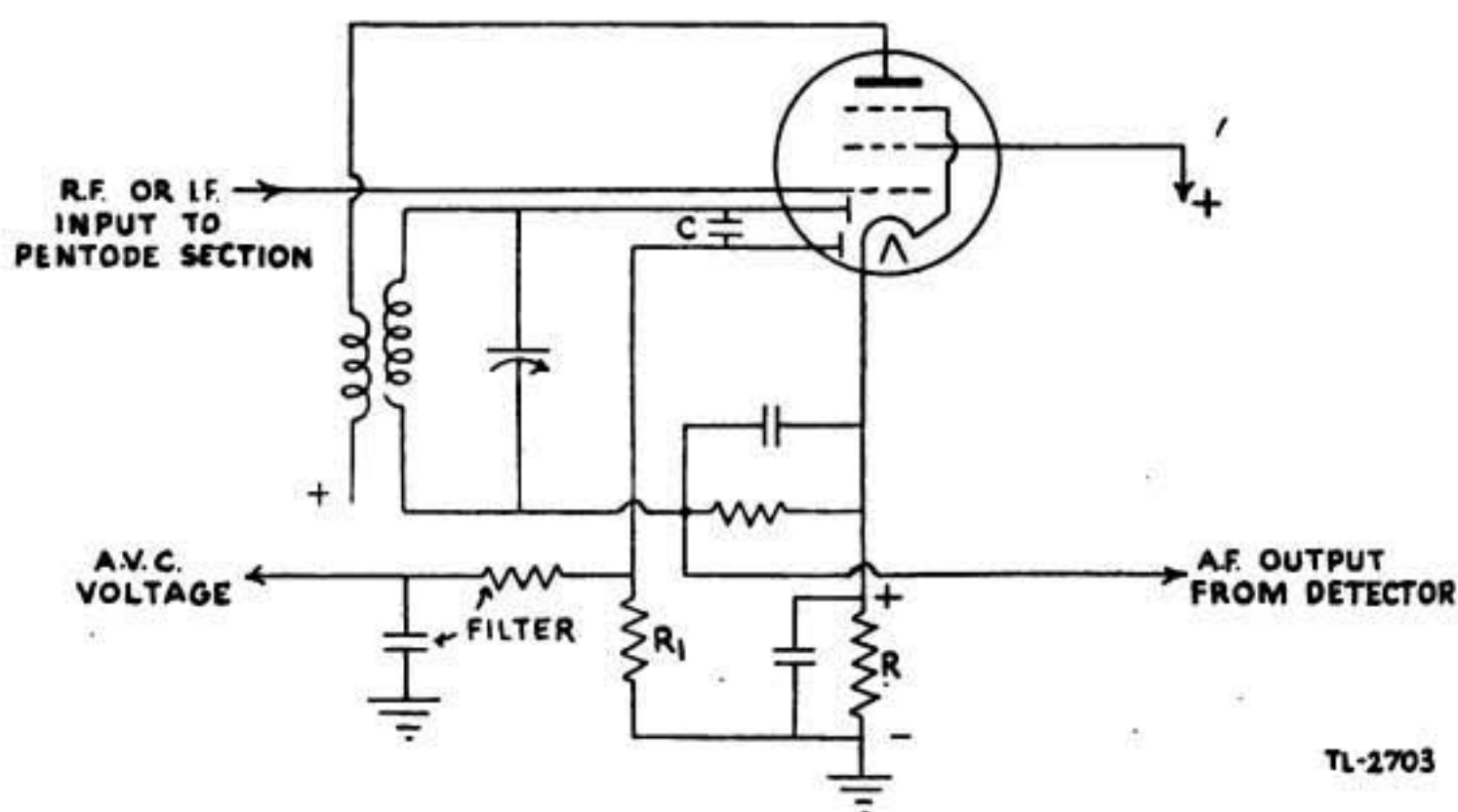


Figure 114. Delayed automatic volume control.

until the peak voltage coupled to it through C counterbalances the negative voltage of the diode. For very weak signals, which do not produce enough voltage on the plate of the a-v-c diode to overcome the existing negative potential, no a-v-c voltage is developed. Thus, the sensitivity of the receiver remains the same as if automatic volume control were not being used. On the other hand, when normal strength signals are being received, which do not need maximum sensitivity of the set, enough voltage will be coupled to the a-v-c diode to overcome the small negative plate potential and produce an a-v-c voltage drop across resistor R . This voltage has the a-f and r-f components filtered from it and is applied to the grids of the variable-mu tubes, as in the ordinary a-v-c circuit.

d. Duplex-diode triode and duplex-diode pentode tubes are widely used to supply a source of a-v-c voltage. In addition, the second diode in these tubes is used, together with the cathode, as a diode-detector

circuit, and the triode or pentode section is used as a separate amplifier. Thus, by the use of such multi-element tubes, the functions of detection, a-v-c voltage rectification, and amplification, is combined within a single tube.

71. A-f Amplifiers

Since the signal output of a detector stage in a t-r-f receiver is low, or weak, it is usual to have at least one stage of a-f amplification. The output of this first a-f amplifier may be further amplified if necessary, depending upon the requirements of the receiver. A headset may require no further amplification after the first a-f stage, while a large loudspeaker may require several additional stages of a-f amplification.

72. Shielding

In order to prevent coupling between two circuits, metal shields are used; iron for a-f circuits, and copper or aluminum for r-f circuits. All shields should be grounded to the chassis of the receiver, which is the *common ground* for all connections in the set. Since shielding changes the inductance of a coil, it changes the resonance frequency to which it responds. It is necessary, therefore, to make many adjustments in radio sets with the shields in place.

73. Circuit of a t-r-f Receiver

a. The complete circuit diagram of a five-tube tuned r-f receiver is shown in figure 115. This receiver uses three pentode r-f amplifier stages, a diode-detector stage, and a pentode a-f amplifier stage energizing a loudspeaker. The *A* supply (heater voltage) and *B* supply (plate voltage) are furnished the vacuum tubes by means of batteries

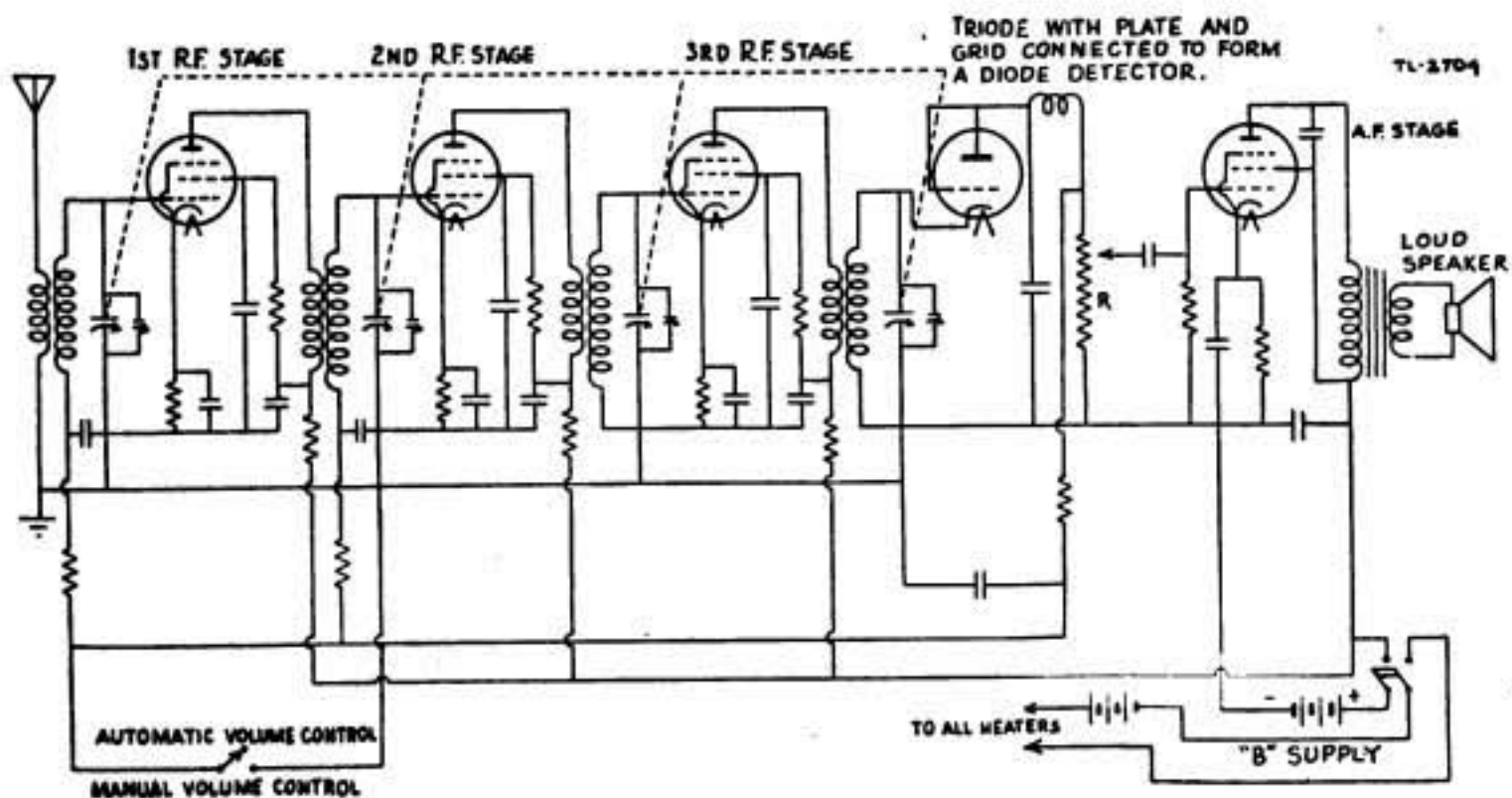


Figure 115. T-r-f receiver with automatic volume control.

when the double-pole single-throw switch is closed. The dotted lines connecting the four tuning capacitors indicate that these capacitors are *ganged*. A small *trimmer* capacitor is connected in parallel with each section of the ganged tuning capacitor for proper alignment of the receiver. These small trimmers compensate for inequalities in any of the circuit constants. The detector stage is considered as a diode, since the grid and the plate are connected together. Figures 116 to 120, inclusive, reproduce this same receiver diagram with various circuits emphasized to facilitate study.

b. In figure 116, all parts of the t-r-f receiver at ground, or chassis, potential are denoted by heavy lines. All points on the heavy (ground) line will be at the same potential, which is considered to be *zero* volts with respect to the rest of the receiver circuit. All voltages in the receiver are compared to this ground potential.

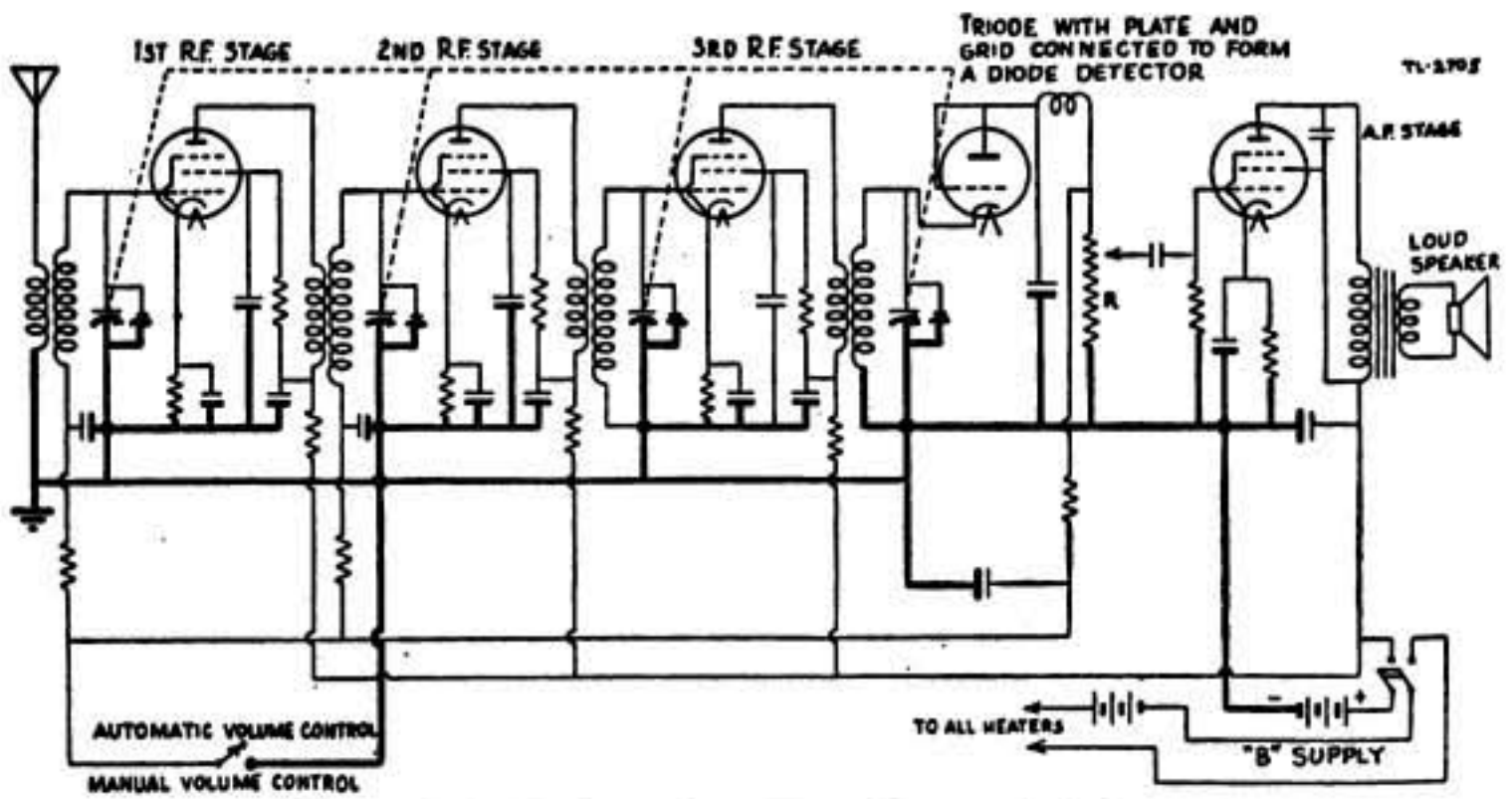


Figure 116. T-r-f receiver. Ground-potential elements denoted by heavy lines.

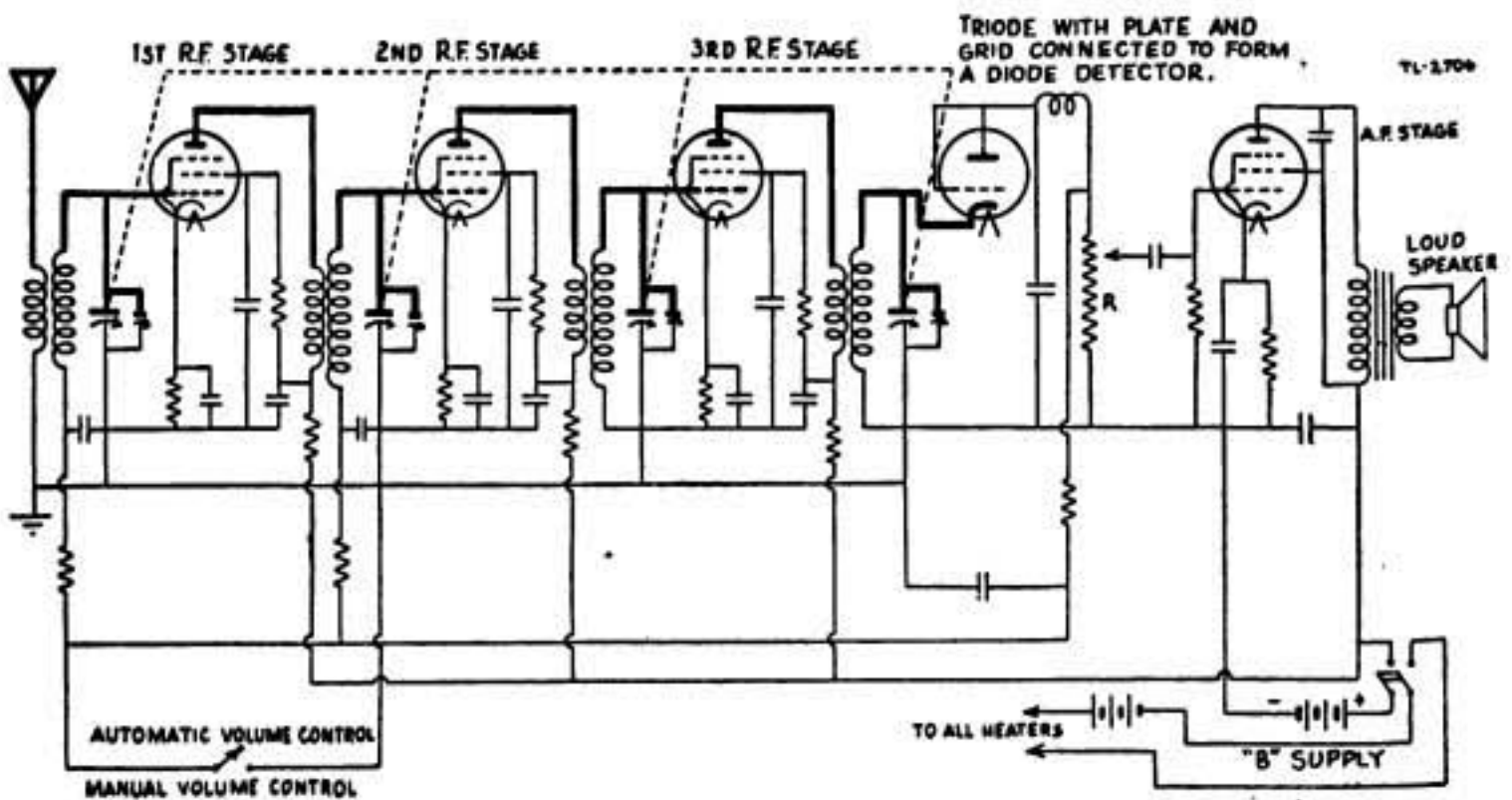


Figure 117. T-r-f receiver. Elements at high r-f potential denoted by heavy lines.

c. In figure 117, all of the elements of the t-r-f receiver at high r-f potential are denoted by heavy lines. By means of this diagram, it is quite simple to trace the path of the r-f signal from the antenna circuit to the diode detector.

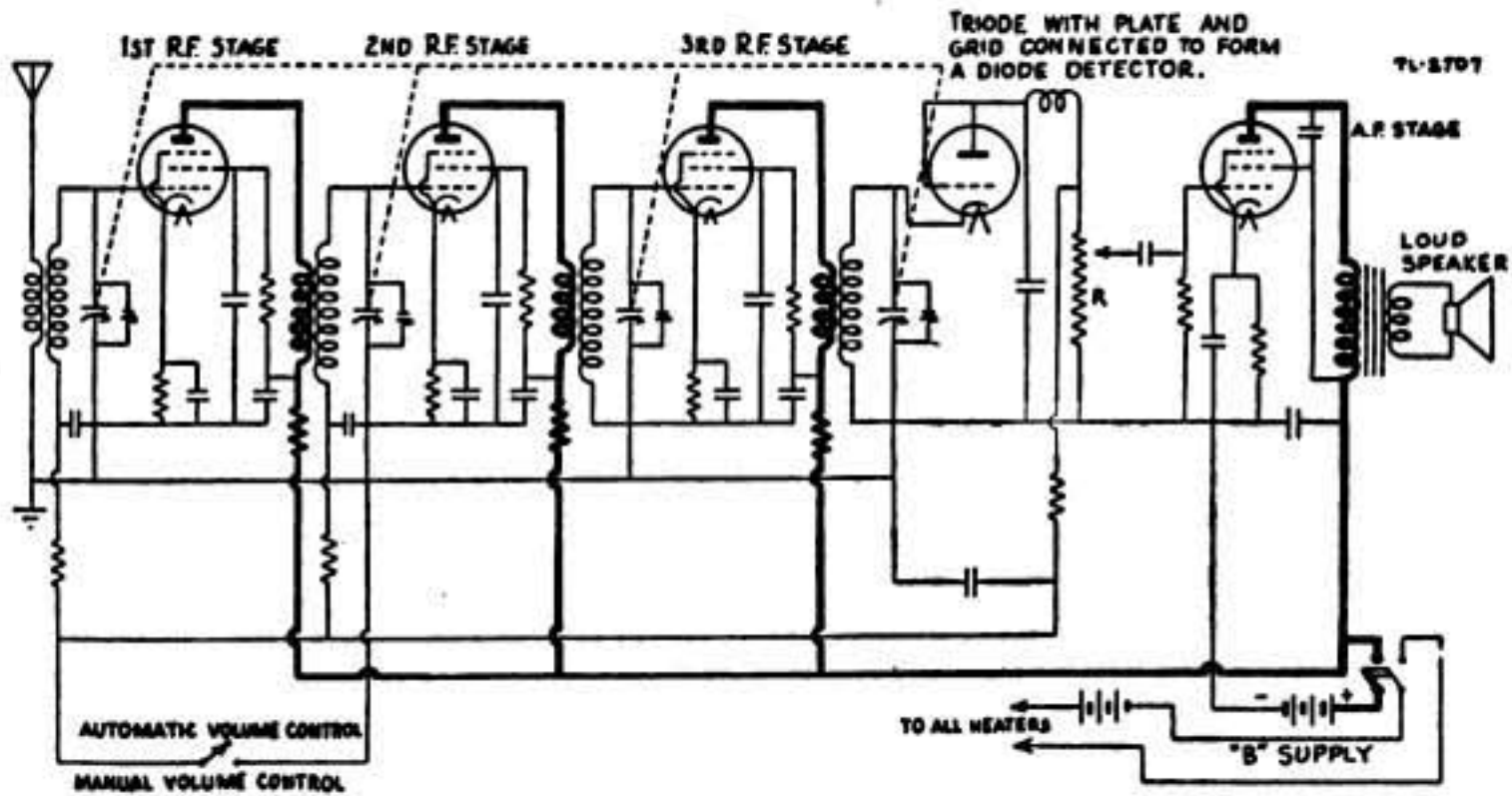


Figure 118. T-r-f receiver. (D-c plate supply shown by heavy lines.)

d. In figure 118, the high voltage d-c plate supply is shown by heavy lines. When the switch is closed, the four pentodes receive the high positive plate voltage necessary for their action as amplifiers. The diode, operating as a detector, does not require d-c plate voltage. Note the decoupling resistors in the plate leads of the first three pentodes.

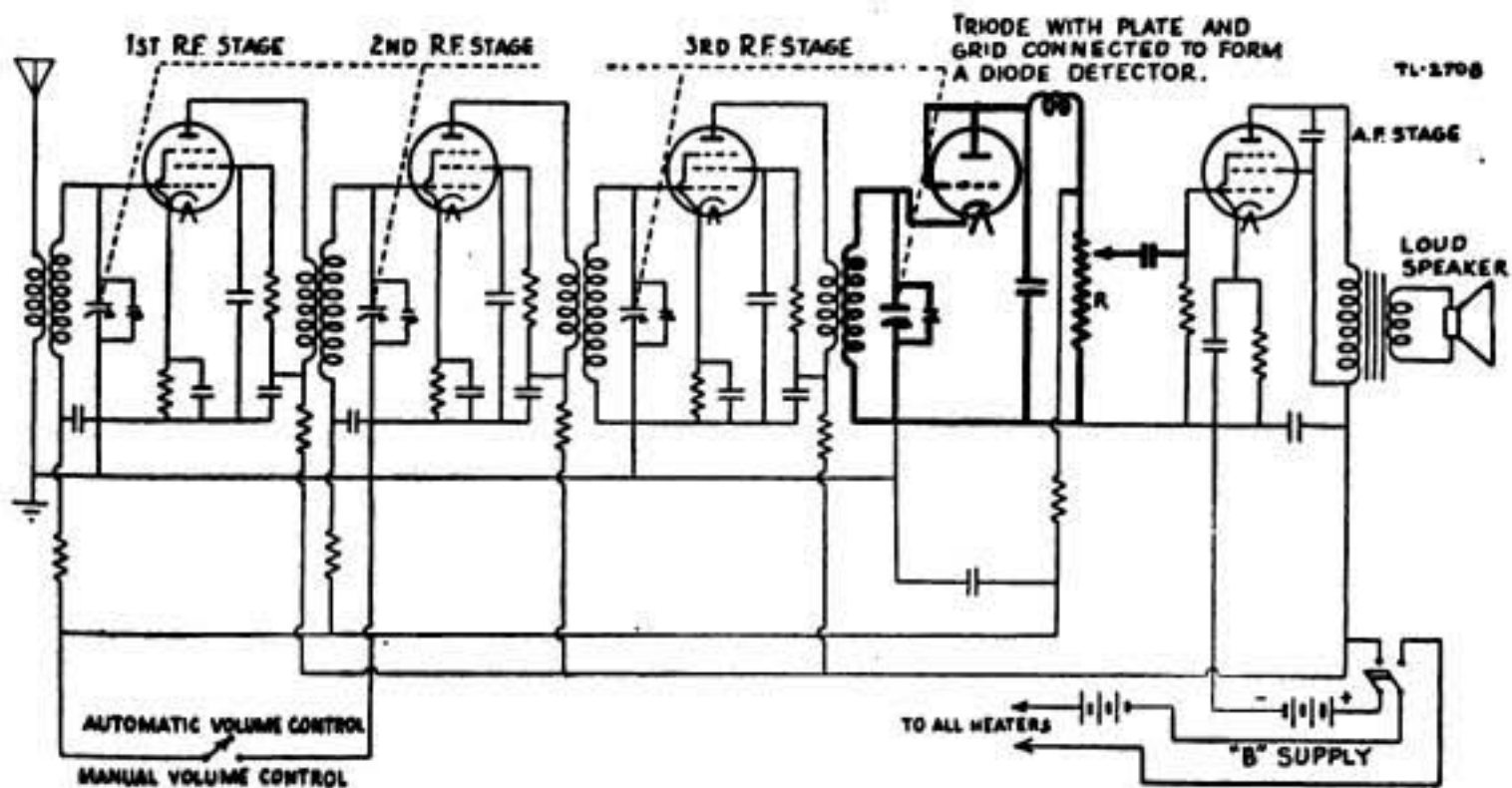


Figure 119. T-r-f receiver. (Detector circuit shown in heavy lines.)

e. In figure 119, the complete detector circuit is shown in heavy lines. The tube used in this stage is considered to be a diode. The grid and the plate of the triode are connected, or *tied* together, resulting in a *two-element tube*, or diode. The rectified or detected signal is taken

from a portion of the potentiometer R (through a capacitor) to the grid of the pentode a-f amplifier.

f. In figure 120, the a-v-c circuit is shown in heavy lines. The rectified signal voltage necessary for the operation of an a-v-c circuit is taken off the negative end of the potentiometer R , and returned to the first two stages of the receiver. It should be noted that only the first and second r-f amplifiers are supplied with an a-v-c voltage in this receiver. A switch is provided for short-circuiting the a-v-c when it is

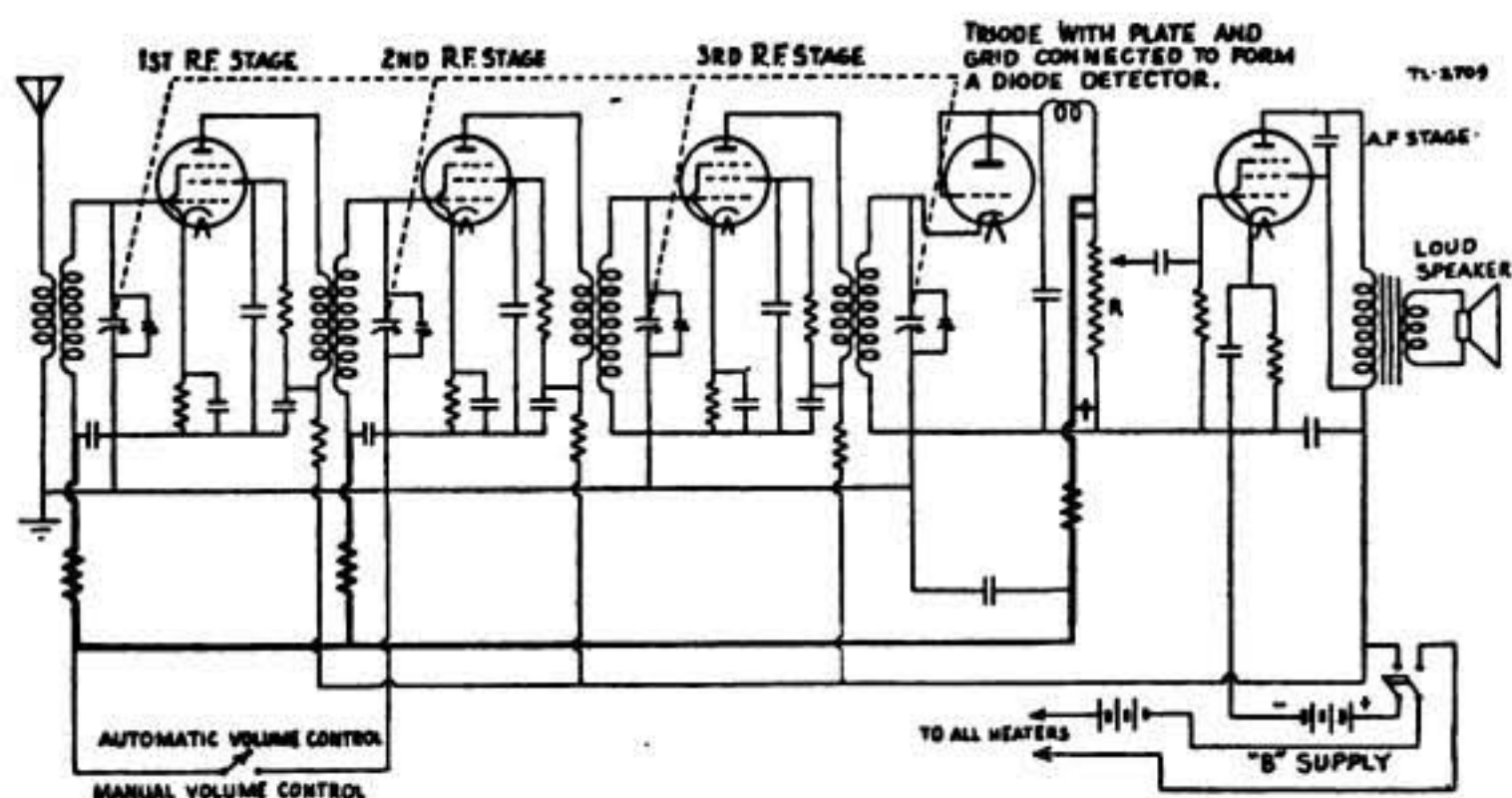


Figure 120. T-r-f receiver. (A-v-c circuit shown in heavy lines.)

not desired. If this is done, the potentiometer R is then used as a *manual* control of volume without affecting the normal operation of the t-r-f receiver.

74. Capabilities of t-r-f Receiver

Although the t-r-f receiver will give satisfactory results when covering a single low- or medium-frequency band, such as the broadcast band, it has several disadvantages which make it impractical for use in high-frequency or multi-band receivers. The chief disadvantage of the t-r-f receiver is that its *selectivity* (ability to separate signals) does not remain constant over its tuning range. As the set is tuned from the low-frequency end of its tuning range toward the higher frequencies, its selectivity *decreases*. At the high frequencies, which are widely used for Signal Corps communication, this lack of selectivity becomes extremely troublesome. Also, the amplification, or gain, of the t-r-f receiver is not constant with frequency. It is very difficult to design r-f amplifiers which will provide sufficient amplification for communication requirements at extremely high frequencies. The super-heterodyne receiver has been developed to overcome these disadvantages.

SECTION VIII

SUPERHETERODYNE RECEIVER

75. Principles of Superheterodyne Operation

a. The essential difference between the t-r-f receiver and the superheterodyne receiver is that in the t-r-f receiver the r-f signal is amplified at the frequency of the signal, while in the superheterodyne receiver the signal is amplified at a new, lower frequency called the *intermediate frequency*.

b. The deficiencies of the t-r-f receiver (par. 74) are largely overcome in the superheterodyne receiver by combining the received signal with a different frequency in the receiver to produce a lower intermediate frequency. Though much lower than the original, this new frequency retains all the modulation characteristics of the old signal. By amplifying this lower frequency, it is possible to use circuits which are more selective and capable of greater amplification than the circuits

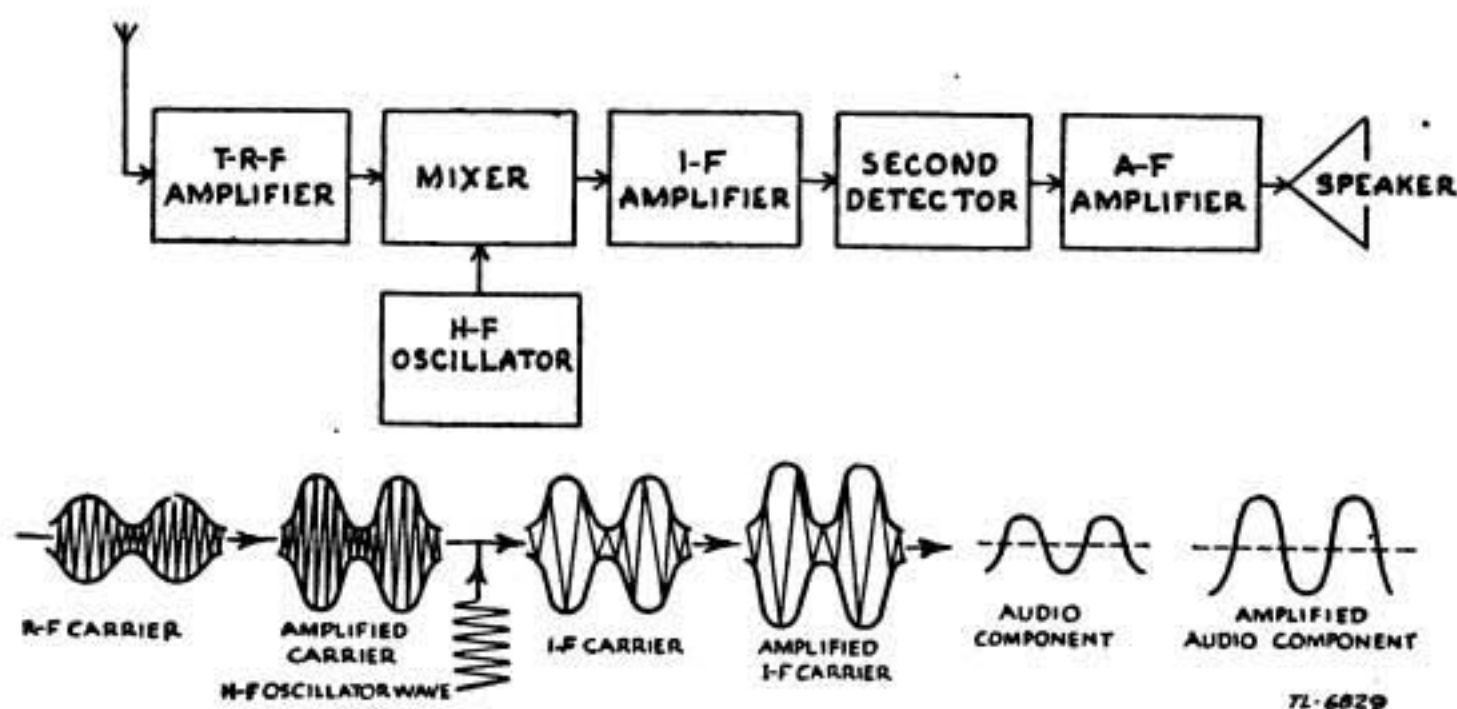


Figure 121. Block diagram of superheterodyne receiver, showing signal passing through receiver.

used in t-r-f receivers. The block diagram of a typical superheterodyne receiver shown in figure 121 indicates the manner in which the signal changes as it goes through the different stages. The received r-f signal is first passed through a r-f amplifier. A locally generated unmodulated r-f signal is then mixed with the carrier frequency in the mixer stage. This produces an intermediate frequency signal which contains all the modulation characteristics of the original signal, but is much lower

in frequency. This intermediate frequency is amplified in one or more stages, called *intermediate-frequency* amplifiers, and is then fed into the *second detector*, where it is detected or demodulated. The detected signal is amplified in the a-f amplifier and then fed to a headset or loudspeaker.

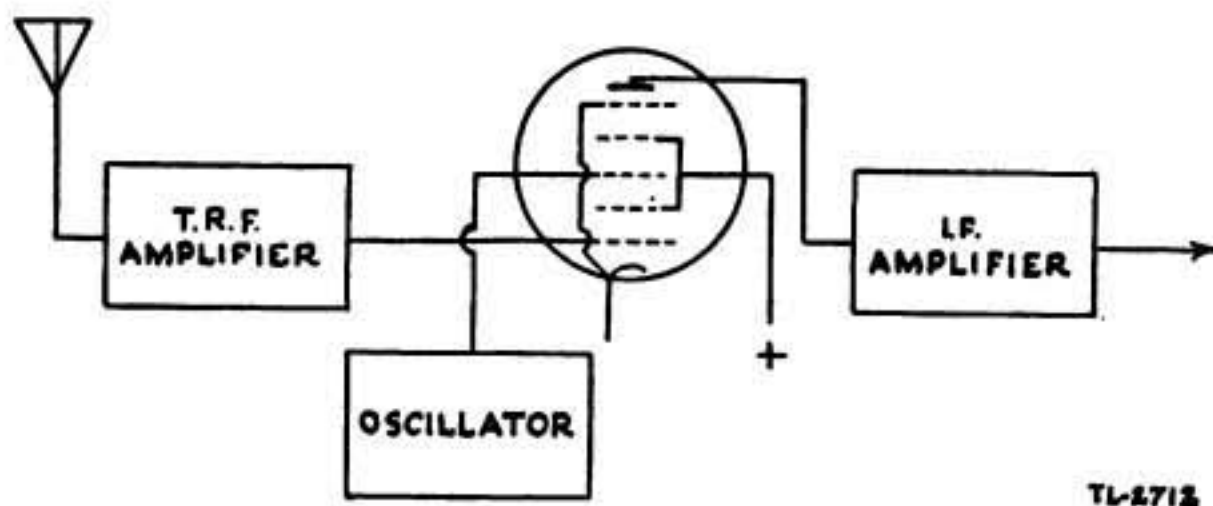
c. The conversion of the original r-f signal to the intermediate frequency is an important function of the superheterodyne receiver. By means of a vacuum tube operating as a detector, it is possible to change the frequency of a radio signal to *another* frequency, and yet retain everything that existed in the original signal. This process is known as *frequency conversion*. The tube is called a *mixer*, or *converter*, and sometimes a *first detector*. If a 1,000-kilocycle signal and 1,465-kilocycle signal are fed into a mixer, various frequencies are obtained in the output. One of the most prominent of these is the *beat frequency*, which is the difference between the two, or 465 kilocycles. *This is the intermediate frequency*. In the superheterodyne receiver these two signals come from different sources. One of them is the received signal. The other comes from a special stage used in all superheterodynes, known as the *local*, or heterodyne oscillator. Unlike the received signal, the signal from the heterodyne oscillator is unmodulated. In the superheterodyne receiver the intermediate frequency is set at a definite value. The frequency of the local oscillator must differ from that of the signal being received by an amount equal to this intermediate frequency. Thus, as the receiver is tuned to signals of various frequencies, the local oscillator must be tuned simultaneously so that its frequency is always separated from that of the signal by the same amount. For example, if the intermediate frequency is 465 kilocycles, a commonly used frequency, and the range of the receiver is from 500 to 25,000 kilocycles, the oscillator would have to operate over a range of either 35 to 24,535 kilocycles or 965 to 25,465 kilocycles. Whether the oscillator frequencies are higher or lower than the signal, the difference is still 465 kilocycles. The higher range is generally used, except when receiving signals of rather high frequencies. The i-f amplifier stages are permanently tuned to 465 kilocycles.

76. Frequency Conversion

a. The combined circuits of the oscillator stage and mixer stage form the *frequency converter* of the superheterodyne receiver. There are a large number of possible combinations of tubes and circuits which may be employed for frequency conversion. Triodes, pentodes, and multi-element tubes are used in various circuits, and several methods are used to mix the oscillator-output frequency with the incoming-signal frequency in the mixer stage. The oscillator output may be fed into the grid, cathode, or suppressor-grid circuit of the mixer tube; or the coupling may be achieved by means of a special grid built

into the tube for that purpose. Multi-element converter tubes have been designed so that the functions of oscillating and mixing may be combined in one tube; the *pentagrid converter* tube is an example of this widely used type.

b. When the frequency converter uses a separate, *single* tube as a local oscillator, the basic circuit is similar to the diagram shown in figure 122. A pentagrid (five-grid) mixer tube (fig. 122) combines

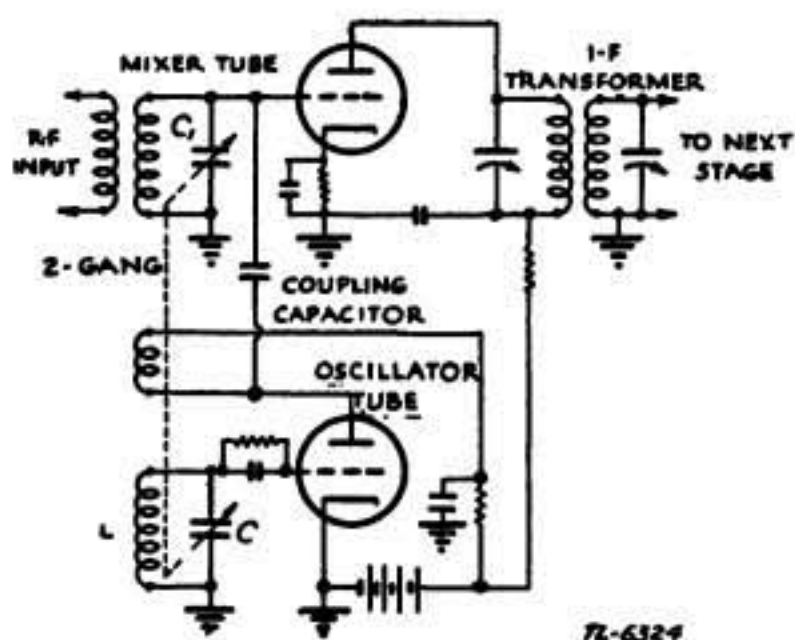


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Figure 122. Pentagrid mixer.

the frequency from the oscillator (usually a triode) with the incoming r-f carrier.

c. A typical frequency-converter circuit using a triode oscillator and a triode mixer is shown in figure 123. The oscillator output is fed or injected into the grid of the mixer through a coupling capacitor. This is known as *grid injection*. The coil and tuning capacitor in the mixer-grid circuit are tuned to the frequency of the incoming r-f signal. The oscillator grid circuit is tuned to a frequency lower or higher than the signal frequency by an amount equal to the intermediate frequency. The i-f transformer in the plate circuit of the mixer stage is tuned



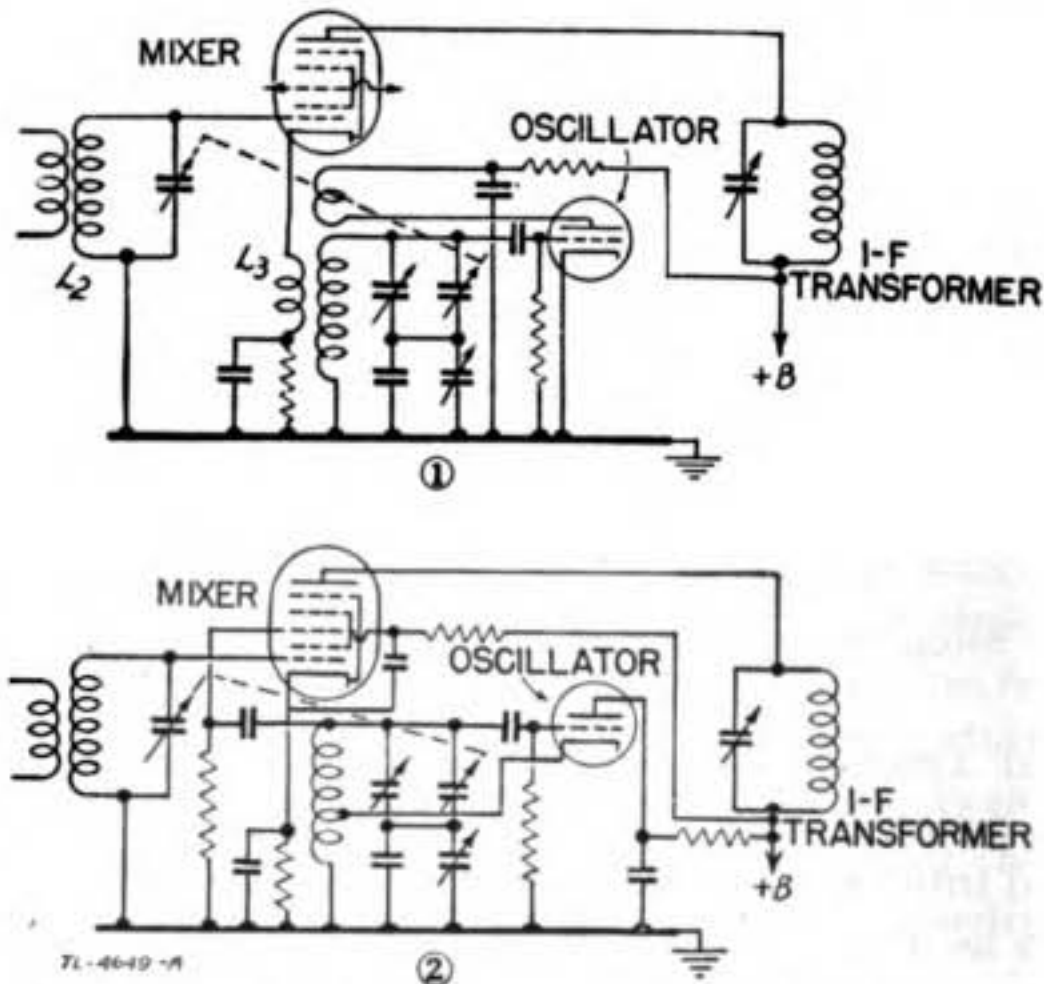
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Figure 123. Frequency-converter circuit using triode oscillator and triode mixer.

to the intermediate frequency. The oscillator uses the same circuit as the regenerative detector studied in paragraph 54. The feedback is of such a value that the circuit is oscillating at a frequency determined

by the values of L and C . The capacitors C and C_1 are ganged so that, as the frequency of the signal being received is changed, the oscillator frequency will also be changed.

d. Two other means of coupling the mixer and local oscillator are shown in figure 124, where a pentagrid mixer and triode oscillator are used. Figure 124① shows the local oscillator coupled to the mixer tube by means of coil L_3 in the cathode circuit of the mixer tube. The



① By means of coil L_3 in cathode circuit of mixer tube.
 ② By means of injection grid of mixer tube
 Figure 124. Local oscillator-to-mixer coupling methods.

r-f voltage induced in coil L_3 causes the plate current of the mixer tube to fluctuate at this frequency. The incoming signal induced in coil L_2 in the grid circuit of the mixer also affects the plate current. These two frequencies are mixed together and the beat between them, which is the i-f frequency, will be produced in the tuned plate circuit. *Interaction* between the oscillator and mixer is reduced somewhat by coupling the oscillator voltage to the cathode, as shown. Figure 124② shows a second method of frequency-conversion coupling between a pentagrid mixer having two independent control grids and a separate local-oscillator tube. Besides a heater and a cathode, the tube has five concentric grids and a plate. Grid 1, which is nearest the cathode, and grid 3 are the control grids of the tube, while grids 2 and 4 are screen grids. Grid 5 is a suppressor grid. The local oscillator is coupled to grid 3, and the incoming signal is applied to grid 1, which is called the signal grid. The voltages applied to these grids affect the plate current, thus producing a beat note or intermediate frequency in the plate circuit of the tube. This tube provides superior performance in

the high-frequency bands because of the excellent shielding between the oscillator and signal grids.

e. Another type of frequency conversion employs a single tube having the oscillator and frequency mixer combined in the same envelope. This type of tube also has five grids, and is called a *pentagrid converter*. The basic circuit for the pentagrid converter is shown in figure 125, and should be compared with the diagram in figure 122. The pentagrid converter depends on the electron stream from the cathode for coupling. It may be visualized as a device in which the plate current is modulated by variations in the cathode emission. The performance of a pentagrid converter is such that only one tube is necessary for converting the

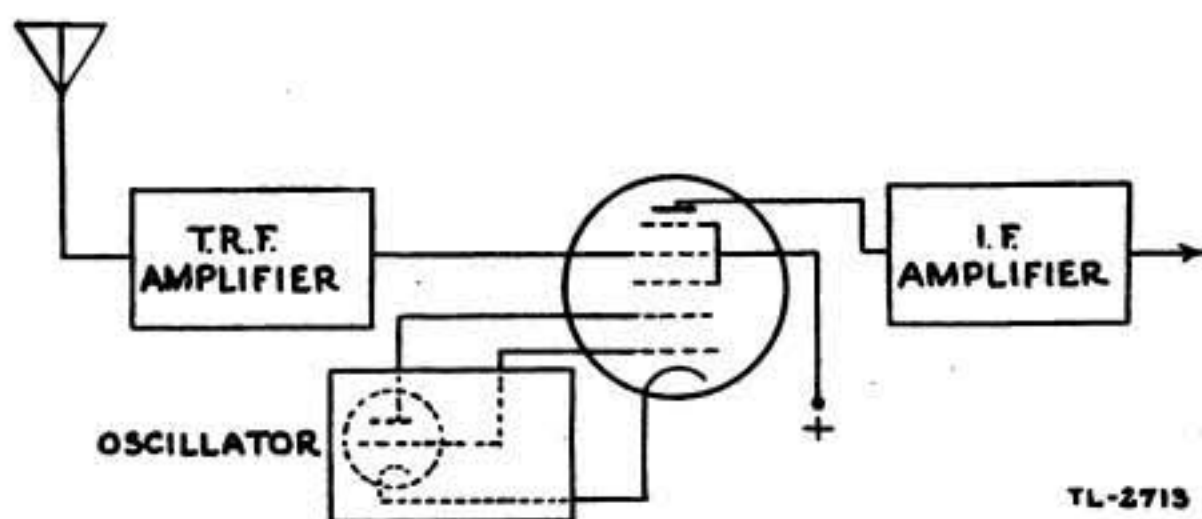


Figure 125. Pentagrid converter.

frequency of the desired signal from its original value to an intermediate frequency. Grids 1 and 2, and the cathode are connected to a conventional oscillator circuit and act as a triode oscillator. Grid 1 is used as the grid of the oscillator, and grid 2 is used as the plate. In this circuit, the two grids and the cathode can be considered as a composite cathode, which supplies to the rest of the tube an electron stream that varies at the oscillator frequency. The signal voltage is applied to grid 4, which further controls the electron stream so that the plate-current variations are a combination of the oscillator and the incoming-signal frequencies. The plate circuit of the pentagrid converter is tuned to the desired intermediate frequency. Grids 3 and 5 are connected together within the tube so as to form a screen grid which serves to accelerate the electron stream and to shield grid 4 electrostatically from the electrodes.

f. A typical pentagrid-converter circuit is shown in figure 126. The incoming r-f signal is fed from L_1 into the tuned grid circuit of L_2 and C_1 . It is then applied to the control grid of the tetrode section of the tube at grid 4. In the oscillator section of the tube, the r-f energy is fed back from the plate circuit inductance L_4 to the tuned grid circuit consisting of L_3 , C_2 , and C_4 . C_2 is the main tuning capacitor. Grid bias for the tetrode section of the tube is secured by the flow of plate current through the cathode resistor R_2 . The incoming signal, and the

oscillator voltages are heterodyned in the electron stream flowing from cathode to plate. The output voltage is a beat frequency equal to the difference between the incoming signal and the oscillator frequencies.

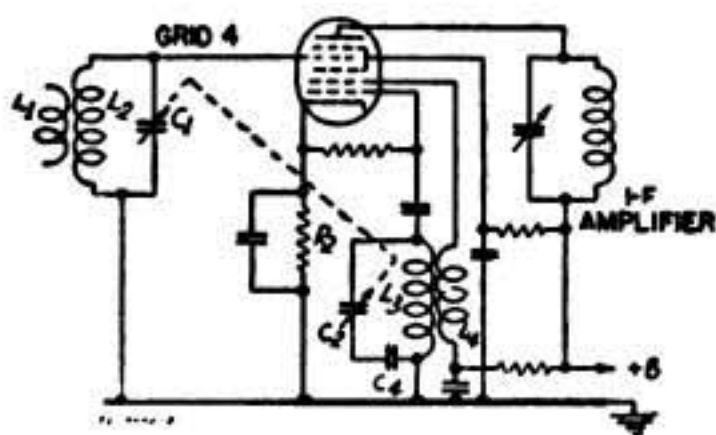


Figure 126. Coupling of oscillator to mixer by means of modulating electron stream from cathode of mixer tube.

g. The capacitor C_4 , placed in series with the tuning capacitor C_2 , is called a *padding capacitor*. This padding capacitor is necessary because the frequency of the oscillator tuned circuit is *higher* than that of the r-f circuit. It is thus necessary to have a low value of inductance and capacitance in the oscillator circuit in order to obtain a higher frequency. In some superheterodyne sets, this is accomplished by having a smaller capacitor and coil in the oscillating circuit. In others, such as in figure 126, it is more convenient to use the same size capacitors in both circuits and reduce the value of the oscillator capacitor by placing a fixed or variable capacitor in series with it. A small trimmer capacitor may also be placed across the oscillator tuning capacitor to take care of any slight frequency deviations.

77. I-f Amplifiers

a. The intermediate-frequency amplifier is a high-gain circuit permanently tuned to the frequency difference between the local oscillator and the incoming r-f signal. Pentode tubes are generally used in these amplifiers, which may consist of one, two, or three stages. Each stage is adjusted to the selected intermediate frequency. Since all incoming signals are converted to the same frequency by the frequency converter, this amplifier operates at only one frequency. The tuned circuits, therefore, may be permanently adjusted for maximum amplification and desired selectivity. It is in this amplifier that practically all of the voltage amplification and selectivity of the superheterodyne is developed.

b. The i-f transformers used with i-f amplifiers are tuned by adjustable, or trimmer, capacitors to the desired frequency. Both mica and air-trimmer capacitors are used. Generally the i-f transformers are double tuned, that is both primary and secondary coils are tuned to the proper frequency. For special applications, single-tuned i-f trans-

formers are used, in which case the secondary winding alone is tuned. I-f transformers are made with both air and powdered-iron cores. Some iron core i-f transformers have fixed mica tuning capacitors. The tuning is accomplished by moving the iron cores in or out of the coil by means of an adjusting setscrew. This is known as *permeability tuning*. The i-f transformers and capacitors are mounted in small metal cans, which serve as shields. When adjustable capacitors and fixed inductors are used, the capacitors are small compared with the large ganged tuning capacitors used in r-f stages. Small adjusting shafts protrude from the top of these capacitors and can be reached through a small hole in the can with a hexagonal wrench or screw driver. Thus, adjustment of the capacitor is possible without removing the assembly from the shield.

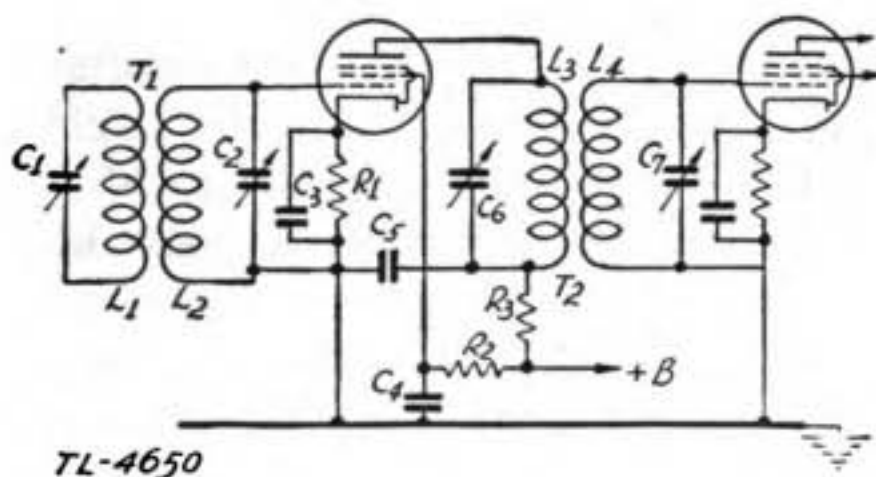


Figure 127. Circuit diagram of single-stage i-f amplifier using pentode tube.

c. The diagram of a single-stage i-f amplifier using a pentode tube is shown in figure 127. Transformer T_1 is the input i-f transformer. The primary of the transformer, L_1-C_1 , is in the plate circuit of the mixer and is tuned to the selected intermediate frequency. The secondary circuit, L_2-C_2 , which is inductively coupled to the primary, is tuned to this same frequency and serves as the input circuit to the grid of the tube. Resistor R_1 in the cathode circuit provides the necessary grid-bias voltage, while capacitor C_3 bypasses r-f currents around this resistor. Resistor R_2 and capacitor C_4 are the screen-voltage-limiting resistor and the screen bypass capacitor, respectively. Resistor R_3 and capacitor C_5 serve as a decoupling network to prevent any of the signal currents from flowing back through the circuit and causing interaction between stages. Capacitor C_5 furnishes a low-impedance path to the cathode or ground for the signal currents, while resistor R_3 prevents any of the signal currents from flowing to the plate supply. These decoupling networks may be employed in grid, screen-grid, or plate circuits. Circuit L_3-C_6 is the tuned-primary circuit of the second i-f transformer T_2 . The secondary circuit L_4-C_7 is coupled to the primary, and is the input circuit of the next tube, which may be another i-f

amplifier or the second detector. The two resonant circuits of the second i-f transformer T_2 are tuned to the same frequency as the circuits in T_1 .

d. Since the i-f amplifier is intended to furnish most of the gain of the superheterodyne the number of i-f amplifier stages used will depend generally on the sensitivity required of the receiving set. From one to three i-f amplifier stages will be found in modern superheterodyne receivers.

e. The intermediate frequency of a superheterodyne will depend, in general, on two factors, the first of which is the desired selectivity. The higher the intermediate frequency, the broader (or less selective) will be the tuning of the receiver. The second factor is the difference between the signal frequency and the intermediate frequency. It is not practical for the intermediate frequency to be very much lower than the signal frequency. For this reason, receivers used on the extremely high frequencies often use a fairly high intermediate frequency. The most common intermediate frequency is in the neighborhood of 456 to 465 kilocycles, although frequencies as low as 85 kilocycles, and as high as 12,000 kilocycles, are found in receivers designed for special purposes.

f. If extremely sharp tuning is required of a receiver, a *piezoelectric quartz crystal* may be used as a *crystal filter* in the i-f amplifier. The crystal acts like a tuned circuit but is many times more selective than those made of coils and capacitors. The crystal will operate only on one frequency which is determined by the thickness of the crystal.

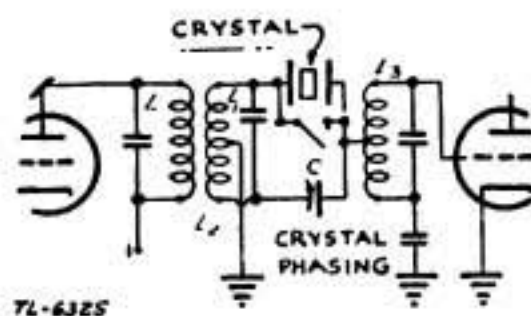


Figure 128. Typical crystal-filter circuit.

A typical crystal-filter circuit used in communications receivers is shown as figure 128. Unless steps are taken to balance it out, the small capacitance between the metal plates of the crystal holder will bypass some undesired signals around the crystal. This balancing is accomplished by taking a voltage from the center-tapped coil L_2 , 180° out of phase with the signal voltage, and applying it through the crystal-phasing capacitor C so that it bucks or neutralizes the undesired signal. The balanced-input circuit may be obtained either through the use of a split-stator capacitor, or by the use of a center-tapped coil as in figure 128. Closing the switch across the crystal shorts the crystal-filter circuit, leaving an ordinary i-f stage. The output of the

crystal filter is applied to a tap on L_3 , which is the input circuit of the next stage, in order to provide the proper impedance match.

g. To keep the intermediate frequency of a superheterodyne centered on its band, automatic-frequency control is sometimes used. This arrangement is useful in compensating for any changes in frequency of the local oscillator. While details of its operation can be understood only after studying section XIII, the principle is not difficult. If the intermediate frequency shifts off the center of its band, that is, varies slightly from its correct frequency, the discriminator (a rectifier) turns the frequency change into a proportionate voltage change. This voltage is fed to a tube in the frequency-control circuit which, together with a capacitor and resistor across the tank circuit of the local oscillator, will change the reactance, but not the resistance of the tank circuit, and hence will change the frequency of the local oscillator. When properly adjusted, any shift in the i-f will be applied through the automatic-frequency control circuit to bring the local oscillator to its correct frequency.

h. Noise limiters are employed occasionally in the i-f circuits of superheterodynes to suppress strong impulses of short duration, such as interference from sparking motor contacts or atmospheric static. In one such noise limiter circuit, a part of the intermediate frequency is diverted along a path paralleling the regular i-f amplifier. It reaches a special detector tube which is so heavily biased that the i-f signal is stopped at this point. If a sudden sharp pulse raises the detector tube above cut-off, the pulse will pass through, and will be fed back out of phase, thus blocking the sudden pulse which will be trying to pass through the regular i-f amplifier.

78. R-f Amplifiers

a. An r-f amplifier is not absolutely necessary in a superheterodyne, but it is a valuable addition for the following reason. If the converter stage were connected directly to the antenna, unwanted signals might be received. These unwanted signals are called *images*. Since the mixer stage produces the intermediate frequency by heterodyning two signals whose frequency difference equals the intermediate frequency, *any two signals whose frequencies differ by the intermediate frequency will produce an i-f signal*. For example, if the receiver is tuned to receive a signal of 2,000 kilocycles and the oscillator frequency is 1,500 kilocycles, an i-f signal of 500 kilocycles will be produced. However, a signal of 1,000 kilocycles finding its way into a mixer will also produce an i-f signal of 500 kilocycles, since the difference between its frequency and the oscillator frequency is 500 kilocycles. Therefore, some method must be found to keep these unwanted signals, or images, out of the mixer stage. The extra selectivity provided by an r-f amplifier is the

solution. Since the r-f amplifier greatly amplifies the desired signal, and does not amplify the image, the possibility of image interference is reduced considerably.

b. Almost all superheterodyne receivers are provided with at least one r-f amplifier stage. The r-f amplifiers used are of the same type as those discussed in section VI. When used in a superheterodyne receiver, r-f amplifiers are sometimes called *preselectors*.

79. Beat-frequency Oscillators

a. In order to receive c-w code signals on a regenerative detector, it will be necessary to make the detector oscillate at a frequency slightly different from that of the incoming signal so as to produce (by heterodyning) an audible signal. (See par. 56.) In superheterodyne receivers, this is done by a separate oscillator, known as the *beat-frequency oscillator*, which is tuned to a frequency that differs from the intermediate frequency by an audible amount. For example, a beat-frequency (b-f) oscillator tuned to 501 kilocycles will produce

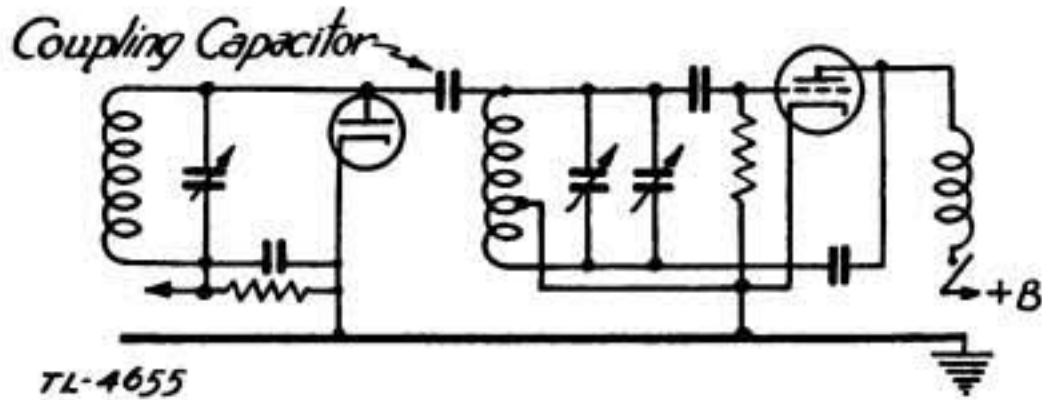


Figure 129. A b-f oscillator coupled to second detector of a superheterodyne.

a beat note of 1 kilocycle, an audible frequency, when heterodyned with a 500-kilocycle i-f signal. The output of this oscillator is coupled to the second-detector stage of the receiver.

b. A b-f oscillator circuit is shown in figure 129. A switch and a means of frequency control are usually located on the front panel of the receiver to turn on the oscillator stage and to control the frequency, or pitch, of the audible signal.

80. Second Detectors

The detectors used in superheterodyne receivers to detect, or demodulate, the intermediate frequency are of the same general types as those employed for t-r-f receivers. Automatic volume control is widely used in superheterodyne circuits. The a-v-c voltage may be applied to any or all of the stages before the second detector except the local oscillator.

81. Audio Amplifiers

The a-f amplifiers used in superheterodyne receivers follow the same general principles as those employed in t-r-f receivers. The desired power output is the main consideration.

82. General Superheterodyne Circuit

a. The circuit diagram of a six-tube battery-operated superheterodyne receiver is shown in figure 130. This receiver has one stage of tuned

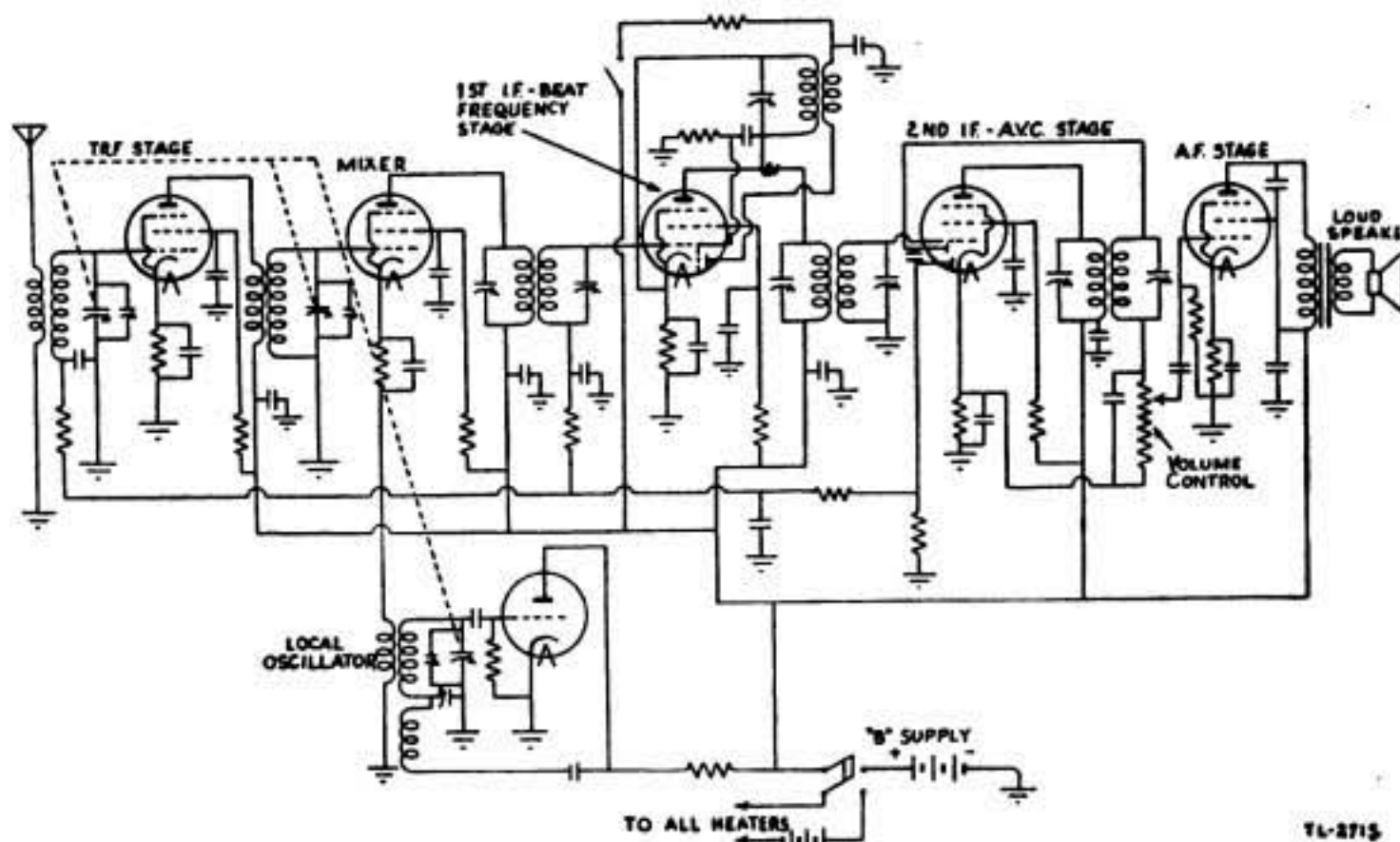


Figure 130. Superheterodyne receiver.

r-f preselection (r-f amplification) a triode acting as a local oscillator, a pentagrid mixer, two stages of i-f amplification, a diode supplying voltage for delayed automatic volume control, a diode detector, and a pentode a-f power-output stage feeding into a loudspeaker. The heater supply and B supply (plate voltage) are furnished to the various stages by means of batteries when the double-pole single-throw switch is closed. The amplifier tubes obtain their grid bias from the resistor and capacitor combination in the cathode circuit of each of the five tubes. The dotted lines connecting the three tuning capacitors indicate that these variable air capacitors are ganged. Small trimmer capacitors are connected in parallel with each of the ganged tuning capacitors for proper alignment of the receiver. The first i-f stage uses a complex tube known as a *triode-pentode*. The pentode section of the tube functions as a straightforward i-f amplifier, and the triode section, operating as an oscillator, can be switched into the circuit to provide a heterodyne action for the audible reception of c-w signals. The second i-f stage combines several functions in one tube known as a *duplex-diode pentode*. This tube contains a pentode i-f amplifier and two diodes, one diode acting as straight signal detector, the other

supplying a rectified a-v-c voltage. Figures 131 through 134 reproduce this same superheterodyne receiver diagram with various circuits emphasized to facilitate study.

b. In figure 131 all parts of the superheterodyne circuit relative to the *second detector* are denoted by heavy lines. A single diode (in the duplex-diode triode tube) supplies an *audio-frequency* signal voltage

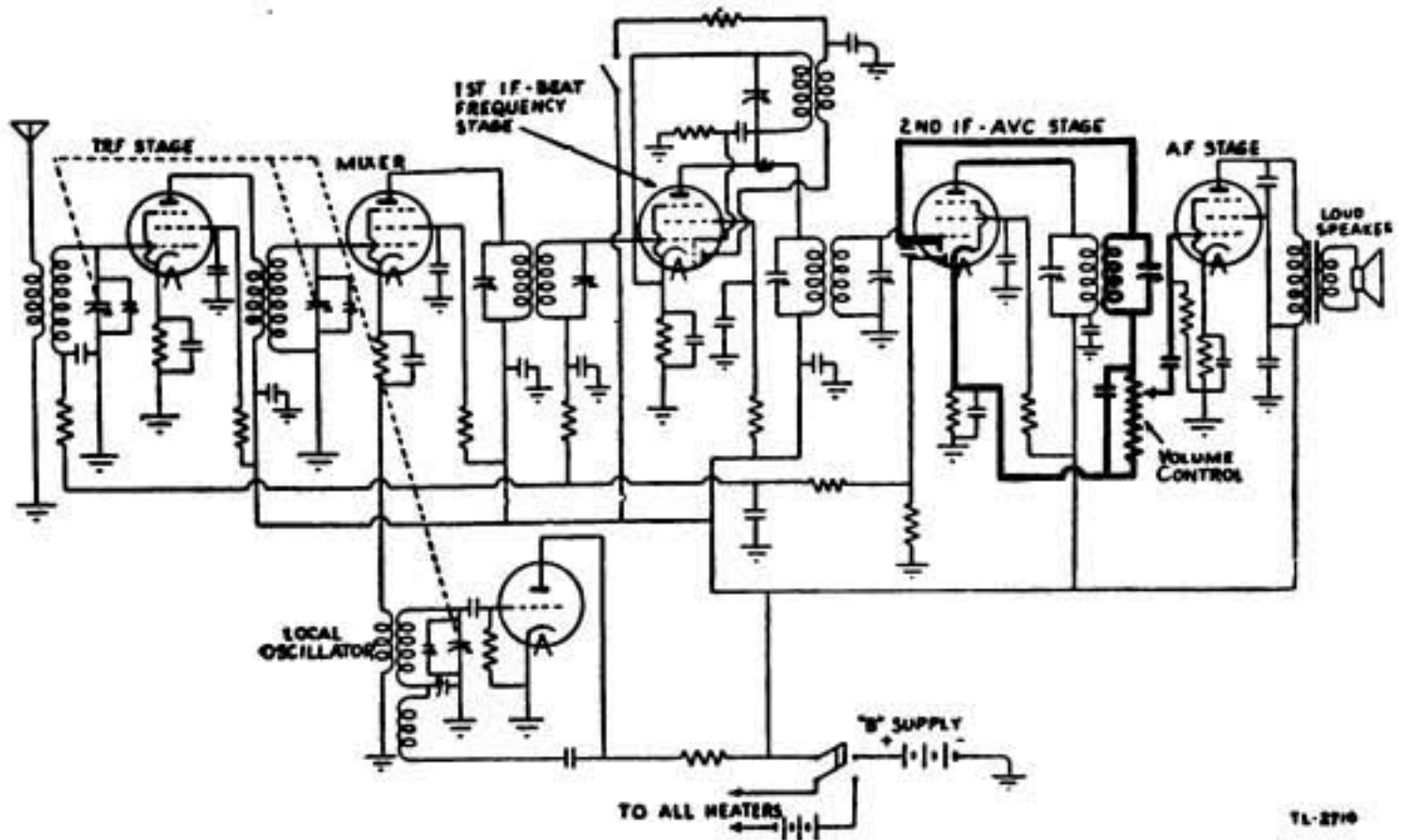


Figure 131. Superheterodyne receiver. (Second detector circuit shown in heavy lines.)

across the variable resistor, or *volume control*. Any portion of this voltage can be fed to the pentode a-f power amplifier, and the level set by the volume control will be maintained by action of the delayed automatic volume control.

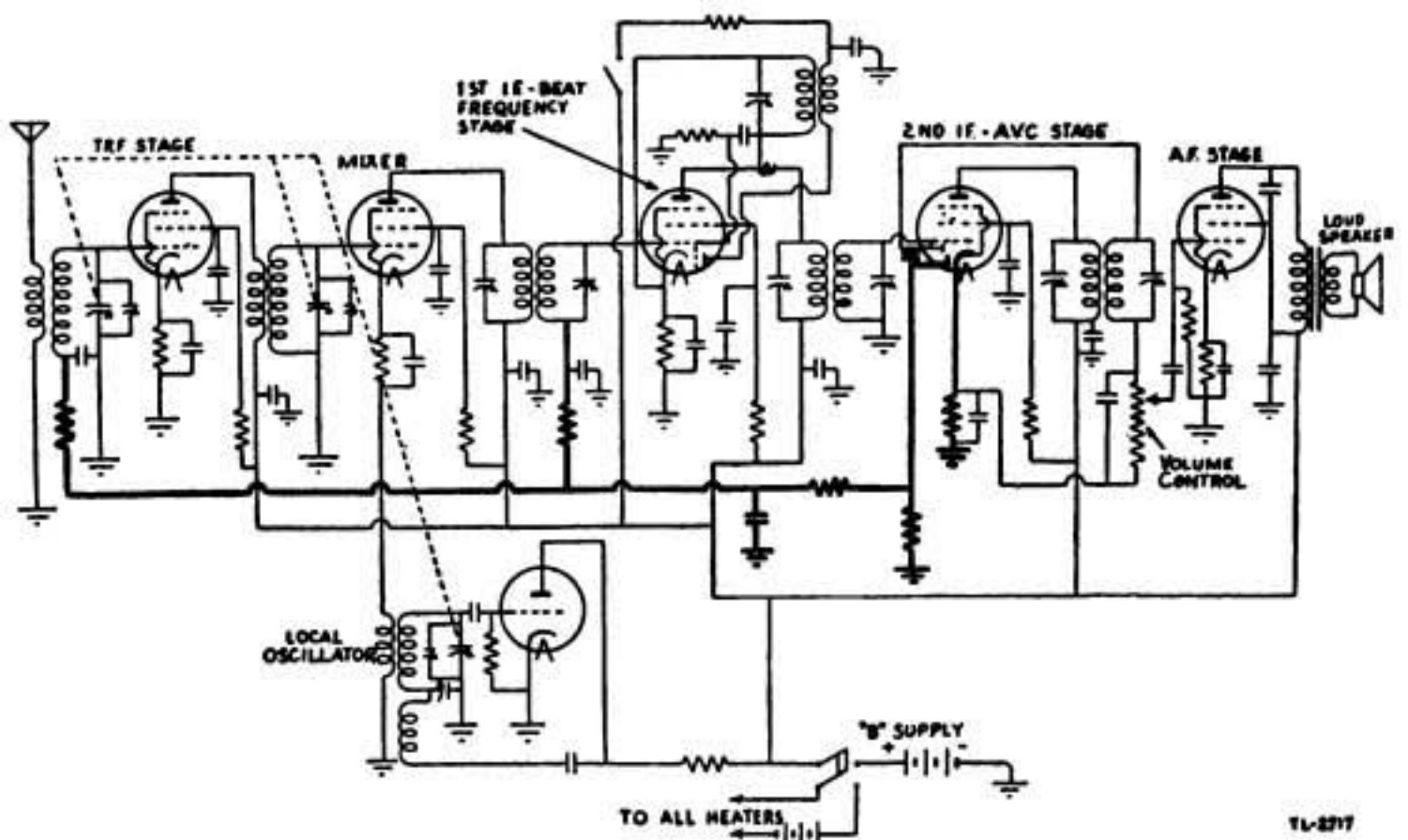


Figure 132. Superheterodyne receiver. (Delayed a-v-c circuit shown in heavy lines.)

c. In figure 132 the delayed a-v-c circuit is shown in heavy lines. The rectified signal voltage necessary for the operation of an a-v-c circuit is obtained by the second diode of the duplex-diode triode. It is passed through isolating resistors, filtered by action of the r-f bypass capacitors, and applied both to the first r-f amplifier stage and the first i-f amplifier stage.

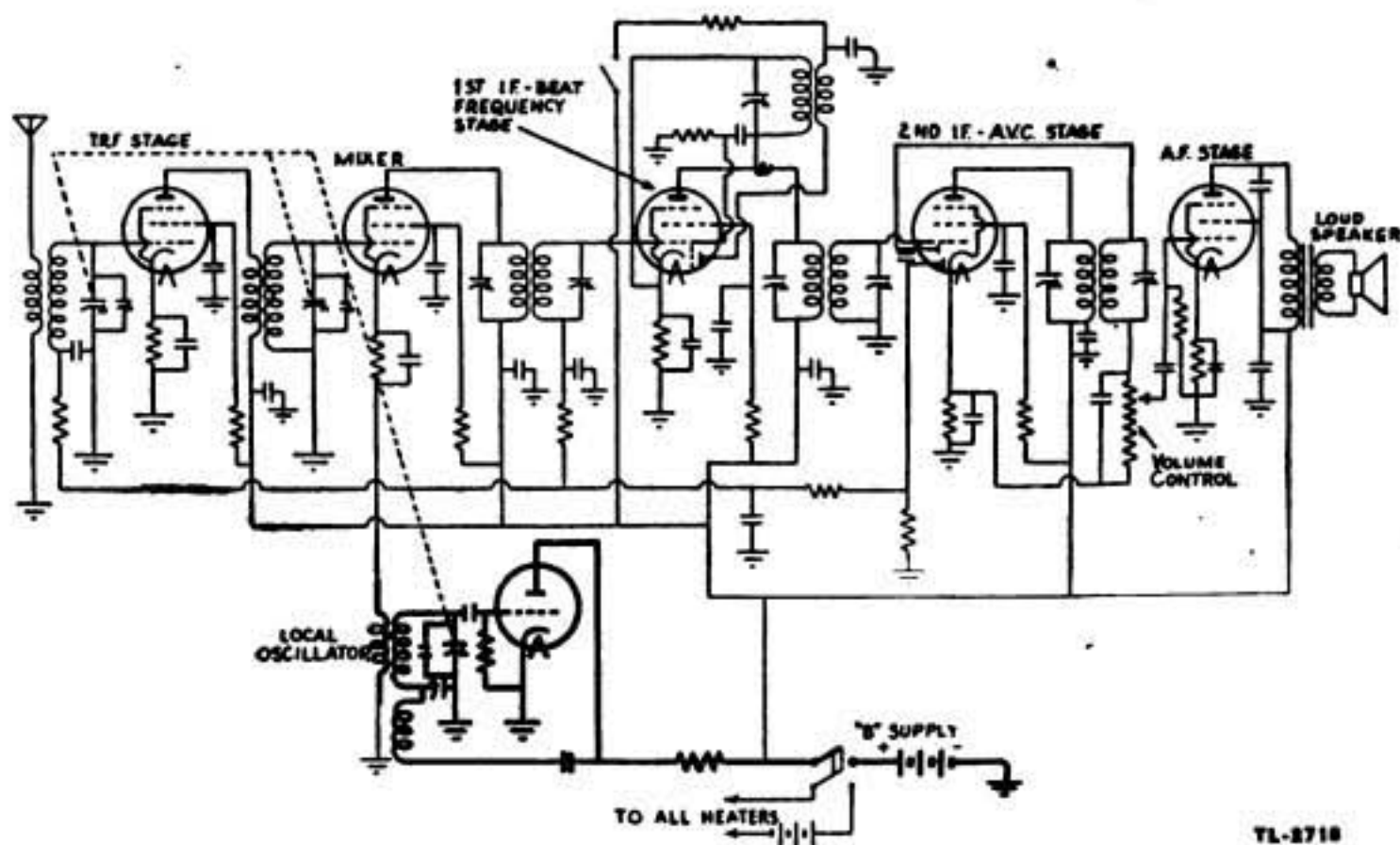


Figure 133. Superheterodyne receiver. (Local oscillator shown in heavy lines.)

d. In figure 133 the local oscillator circuit is shown in heavy lines. The tuned circuit, which determines the frequency of the local oscillations, is composed of a fixed coil and a variable amount of capacitance,

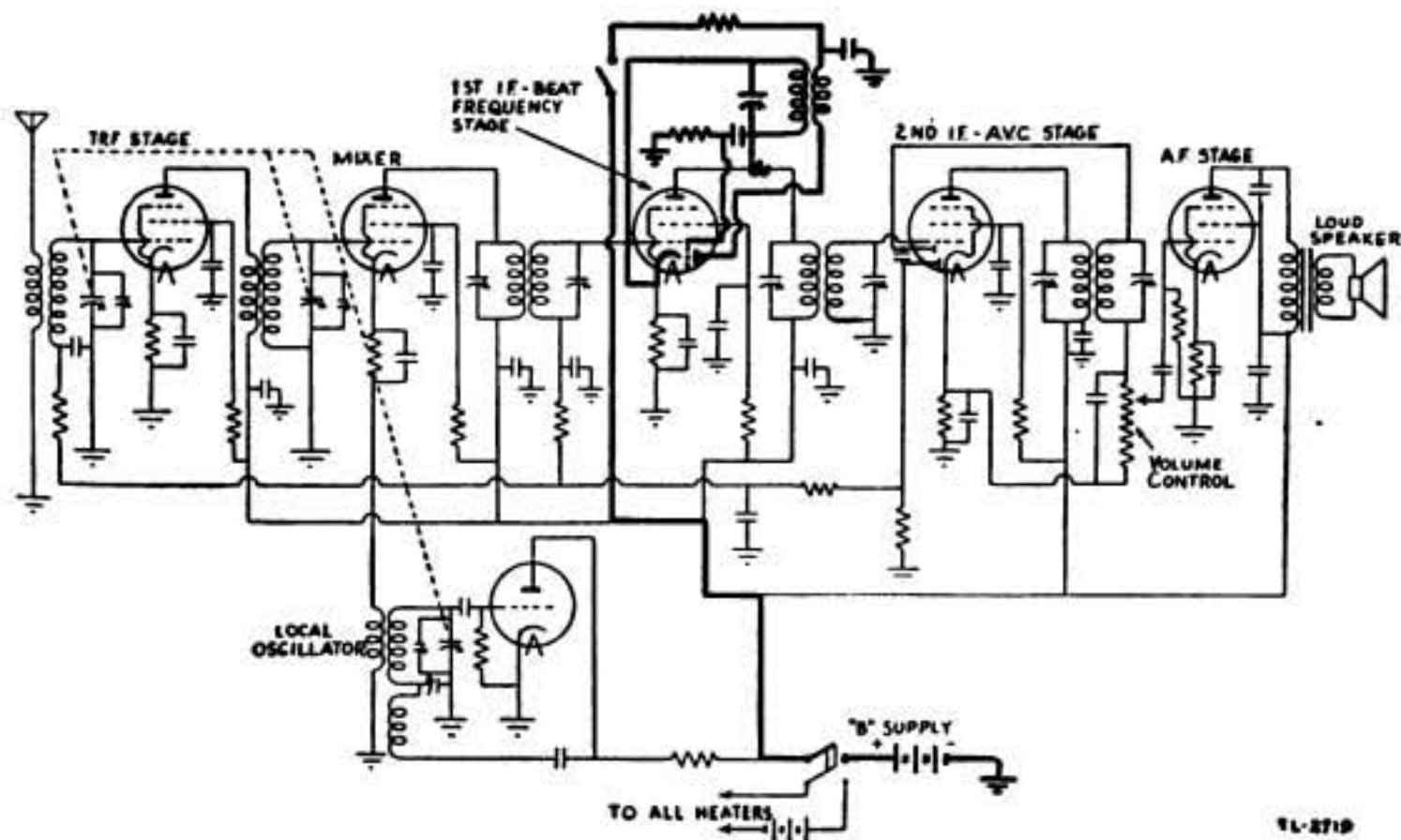


Figure 134. Superheterodyne receiver. (B-f oscillator for c-w reception shown in heavy lines.)

consisting of a variable air-tuning capacitor, an adjustable trimmer capacitor in parallel with the tuning capacitor, and an adjustable padding capacitor in series with the tuning capacitor.

e. In figure 134 the *b-f oscillator circuit* is shown in heavy lines. The pentode section of the first i-f amplifier tube, a triode-pentode, functions as a normal i-f amplifier when the b-f-o power switch is open, as shown in diagram. When this switch is closed, the pentode continues to operate as an i-f amplifier, but oscillations also take place in the triode section of the tube at the frequency of its external tuned circuit. By means of a small variable capacitor, the frequency of this tuned circuit can be altered for different incoming signals, so that the local oscillations produced in the regenerative circuit are only *slightly* different in frequency from the incoming signal. When these two frequencies are mixed in the first i-f amplifier stage, there is a heterodyne action producing an audible signal which can be used for the reception of c-w code.

83. Typical Army Superheterodyne Receiver

a. A complete schematic diagram of a typical Army superheterodyne is shown in figure 135. This receiver is operated from 110 volts alternating current and uses eight vacuum tubes. The r-f signal voltage from the antenna circuit is amplified by a pentode r-f amplifier stage. Another radio frequency generated in the local oscillator stage is mixed with the signal voltage in the pentagrid mixer stage, to create an i-f carrier. This intermediate frequency is amplified by a pentode i-f amplifier stage, and is then detected by the diode detector section of a duplex-diode triode. The resulting a-f signal is applied to the triode section of this complex tube which operates as an *audio-frequency voltage-amplifier stage*. This signal is further amplified by a *push-pull audio-frequency power-amplifier stage* of two pentodes, and then is fed to the loudspeaker. High-voltage direct current for the plates, and low-voltage alternating current for the heaters of the vacuum tubes are obtained from the *power supply stage*, which uses a full-wave rectifier circuit. It should be noted that every tube and circuit element in figure 135 has an identifying number. This is to facilitate a more thorough analysis of the set, as the signal is traced through the receiver from the antenna to the speaker.

b. Assume that the receiver is tuned to a 1,000-kilocycle signal and that the i-f amplifier frequency is 465 kilocycles. The signal is picked up by the antenna and fed to the grid of the r-f amplifier tube (VT-117) through the r-f coupling transformer T_1 . The signal is then amplified by the tube and fed to the r-f coupling transformer T_2 . It is then applied to the control grid (grid 1) of the mixer tube (VT-87). The grid circuits of the r-f and mixer stages are both tuned to the 1,000-kilocycle signal by a single dial controlling the ganged capacitors C_1 and C_2 . C_4 is a bypass capacitor for the grid-decoupling resistor R_1 .

R_2 is the biasing resistor and C_5 the bypass capacitor for R_2 . R_3 is the screen grid voltage-dropping resistor and C_6 is the bypass capacitor for R_3 . R_4 and C_7 constitute the plate current filter which prevents the r-f signal from feeding back through the power supply to ground and thereby producing common coupling between stages. The high-frequency oscillator (VT-65) must generate oscillations 465 kilocycles higher in frequency than the r-f carrier. It is therefore tuned by C_3 (which is ganged with C_1 and C_2) to 1,465 kilocycles. C_{24} is a trimmer for C_3 and C_{26} is a trimmer for C_{25} which is the padder capacitor used to make the oscillator track with the r-f amplifier. R_{22} is the oscillator-biasing resistor and C_{23} is a blocking capacitor used to prevent the oscillator inductor from shorting R_{22} . R_{21} is the oscillator plate voltage-dropping resistor and C_{27} is the bypass capacitor for R_{21} . C_{27} also serves as a blocking capacitor to prevent shorting the plate voltage to

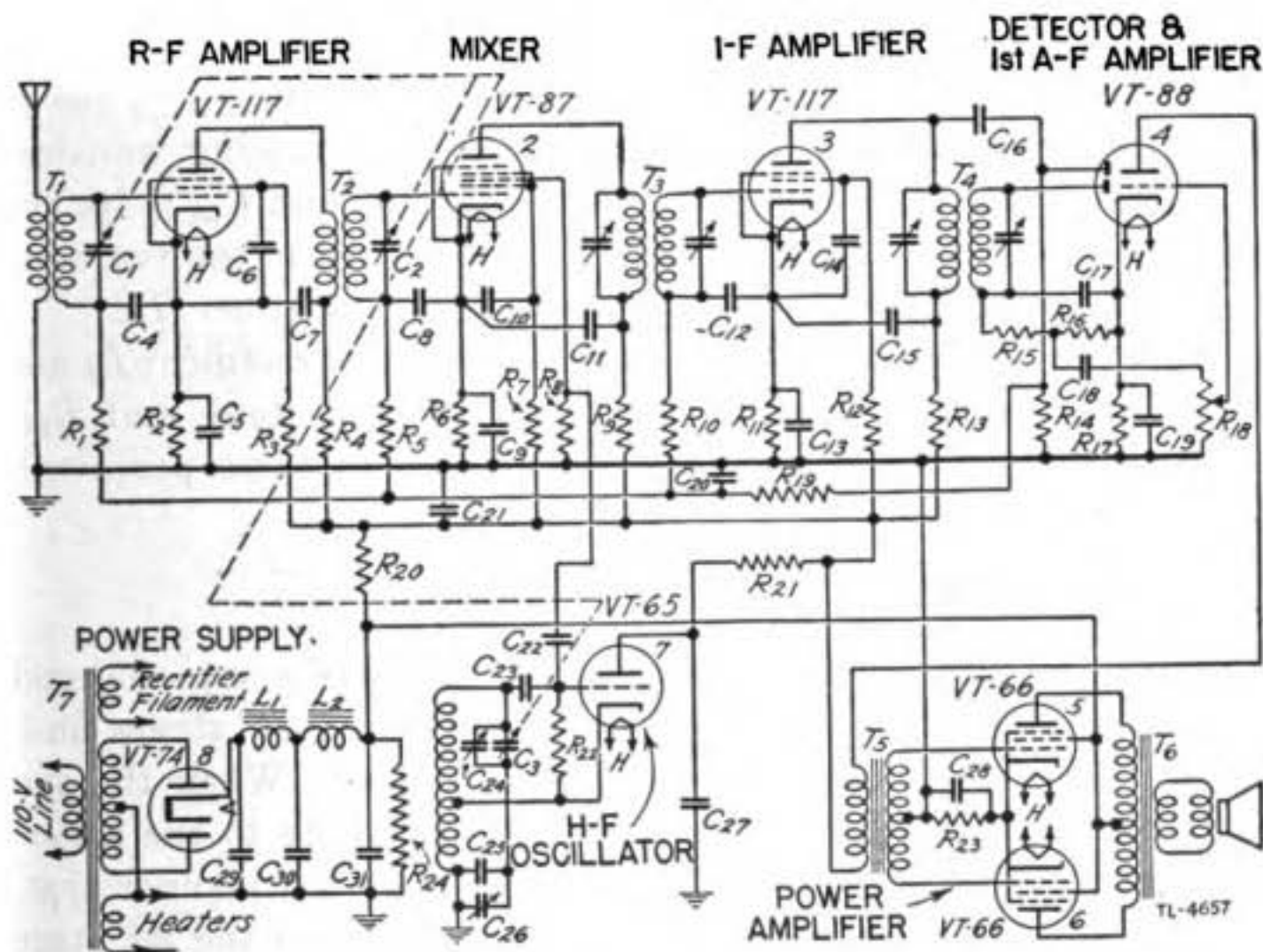


Figure 135. Circuit diagram of a modern Army superheterodyne receiver.

ground. The high-frequency voltage is injected into the electron stream of the mixer tube by grid 3. R_8 is the injector grid-biasing resistor, and C_{22} is the coupling capacitor for the oscillator. The 1,000-kilocycle signal and the 1,465-kilocycle signal are mixed in the electron stream of the mixer stage. The i-f stage functions in the same manner as the r-f stage, except that it always works at the intermediate frequency and therefore is much more efficient than the r-f stage. The i-f transformers T_3 and T_4 are permanently tuned to the 465-kilocycle intermediate frequency, and usually need only occasional checking for correct alignment. The lower diode section of tube 4 (VT-88) is the

detector, with R_{15} and R_{16} as the detector load resistor. C_{17} is the r-f bypass capacitor. With R_{15} it forms an r-f filter to prevent the r-f component of the signal from feeding into the a-f section through the blocking capacitor C_{18} and the volume control R_{18} . The audio signal voltage developed across R_{16} also appears across the volume control R_{18} . All, or a portion, of this voltage, depending on the setting of the variable arm, is fed to the grid of the first audio amplifier (triode section of tube 4). R_{17} is the bias resistor for the first a-f amplifier, and C_{19} is its bypass capacitor. The i-f voltage from the plate of the i-f amplifier tube is fed through the blocking capacitor C_{16} to the upper diode plate, which rectifies the signal voltage to develop the a-v-c voltage. R_{14} is the a-v-c diode load resistor. The d-c voltage developed across this resistor is in series with the r-f amplifier, mixer, and i-f amplifier grid circuits. It is applied to the grids through the a-v-c filter resistor R_{19} . R_{19} and C_{20} act as a filter to eliminate any audio component from this voltage, and thus prevent the grid bias of these tubes from fluctuating at an a-f rate. The output of the first a-f amplifier is fed to the grids of the push-pull amplifier through the interstage-coupling transformer T_5 . R_{23} is the bias resistor for both of these tubes and C_{28} is its bypass capacitor. The output of the power amplifier is fed to the voice coil of the speaker through the output (matching) transformer T_6 .

c. T_7 is the power transformer; tube 8 the power rectifier; L_1 and L_2 the filter chokes; C_{29} , C_{30} and C_{31} the filter capacitors, and R_{24} the bleeder resistor. The specific function of each of these parts will be discussed in section IX.

84. Alignment

a. In order to operate one or several r-f stages of a superheterodyne with a single control, the tuning capacitors of the r-f stages and the oscillator are ganged together on a common shaft. When the control knob is turned, the various r-f stages must all tune to the same frequency and the local oscillator must track in such a manner that the frequency difference between the local oscillator and the r-f stages is always equal to the intermediate frequency. When the circuits are adjusted in this manner, they are said to be *tracking*. The trimmer (parallel) capacitors are used to assure tracking at the high-frequency end of the band, and the padder (series) capacitors are used to assure tracking at the low-frequency end of the band. In general, only the local oscillator is supplied with a padder capacitor. It is also necessary to adjust the i-f stages so that they all tune to the intermediate frequency. Misalignment in any stage of a superheterodyne will cause a decrease of sensitivity or selectivity, or both.

b. A calibrated oscillator or signal generator, insulated screw drivers, insulated adjustment wrenches, and some form of output indicator are necessary to properly align a modern superheterodyne receiver. The

signal generator is an oscillator calibrated in frequency and capable of delivering either a c-w or a modulated signal. Provision is made for controlling the output signal voltage from a few microvolts to the full output voltage. The insulated screw drivers and wrenches are used to adjust the tuned circuits. The screw drivers and wrenches may be of a composition material and usually have bits and heads of metal, which give more substantial service and at the same time place a minimum of metal in the field of the circuit that is being adjusted. The output indicator may be an output meter, loudspeaker, headset, oscillograph, or a tuning-indicator tube.

SECTION IX

POWER SUPPLIES

85. Power Requirements of Radio

a. Vacuum tubes used in various circuits of radio receivers and transmitters require voltages of various values for the filament, screen, and plate circuits. It is the purpose of the power supply to provide these voltages. Except for filament power, which can be alternating current, the output from a power supply must be as nearly pure direct current as possible, and the voltage must be of the correct value for the apparatus for which it is to be used. Radio transmitters require more power than receivers. Consequently, transmitter power supplies operate at higher voltages, with greater current flowing.

b. Power to heat the filaments of tubes is sometimes called the *A* supply, and normally will be a low voltage. In portable field radio sets the cathode, or filament, power supply is furnished by batteries, generators, or dynamotors. Semiportable and mobile sets generally use storage batteries for filament-heating purposes. In permanent ground installations, filaments are heated from the standard a-c lighting circuit through a step-down transformer.

c. The plate and screen power supply is sometimes called the *B* supply, and will usually be a high voltage. The plate supply in a lightweight transceiver (small combined transmitter and receiver) is furnished by batteries. Dynamotors driven by storage batteries or by hand are generally used for plate power in portable and mobile sets, while many large semiportable transmitters carry gasoline-engine-driven generator equipment. Permanent installations ordinarily use some sort of rectifier-filter system plate supply.

d. When a grid-bias voltage is used, it is sometimes called the *C* supply. Grid bias for voltage amplifiers is customarily taken from a part of the plate supply by some means of self-bias. For large power-amplifier tubes a separate rectifier-filter system or d-c generator is frequently employed.

e. Radio power supplies may be divided into three general classes: battery, a-c, and electro-mechanical systems.

86. Battery Power Supply

Small portable receivers and transmitters usually operate from dry batteries. The current drain from the batteries is low and the apparatus

can be operated several hours from this type of supply before it must be replaced. Battery packs containing the filament, plate, and grid batteries are provided for some sets; separate filament, plate, and grid batteries are used in others. Batteries have the advantage of being capable of delivering a smooth, unfluctuating direct current. Where large voltages and currents are required, however, they become cumbersome and expensive.

87. A-c Power Supply

a. This type of power supply is generally used whenever commercial power is available. The Army also uses it for field installations which are equipped with gasoline engine driven generators designed to supply a source of alternating current. An a-c operated power system differs from other types in that no batteries or mechanical devices are used. It makes use of an a-c source of power, and since the usual commercial supply is 110-volt, 60-cycle, this voltage will be assumed in the following discussion of a-c power supplies.

b. All a-c operated power supplies may be divided into four parts: the transformer, rectifier, filter, and bleeder, or voltage divider system. The transformer provides a means of increasing or decreasing the voltage by transformer action. (See par. 27.) The rectifier serves to convert the alternating current to pulsating direct current. The filter smooths out the pulsating direct current, and the voltage divided system is used to obtain various d-c voltages for the plate, screen, and control-grid circuits.

88. Vacuum-tube Rectifiers

a. The diode finds its most important use as a rectifying tube in both transmitter and receiver power supplies. A simple a-c rectifier consisting of a *single* diode is shown in figure 136. When an a-c voltage is applied between points A and B, electrons will flow from the cathode to the plate of the diode during the positive alternation of each cycle (between points 1 and 2 in figure 136①). During the next alternation,

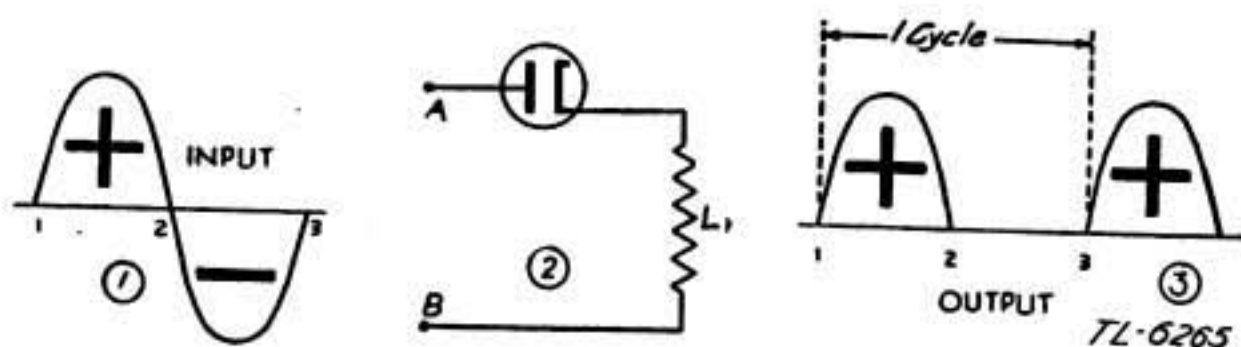


Figure 136. Half-wave rectifier.

between points 2 and 3, the plate voltage is negative with respect to the cathode and no current will flow in the circuit. Thus, since the diode will pass current only during the positive alternation of each

cycle, current will flow in only one direction through load resistor L . Since only one-half of each cycle is used in this type of rectifier, it is called a half-wave rectifier. Figure 136① shows the a-c input and 136③ the pulsating output voltage of a half-wave rectifier. It should be noted that the d-c pulsations have the same frequency as the applied a-c voltage. This makes it difficult to filter properly. If a higher voltage is necessary, a step-up transformer may be used.

b. A full-wave rectifier consists of two half-wave rectifiers working on opposite alternations, thus utilizing the complete cycle of alternating current. The two rectifiers are connected in such a manner that both half-waves are combined in the output, as shown in figure 137. Refer-

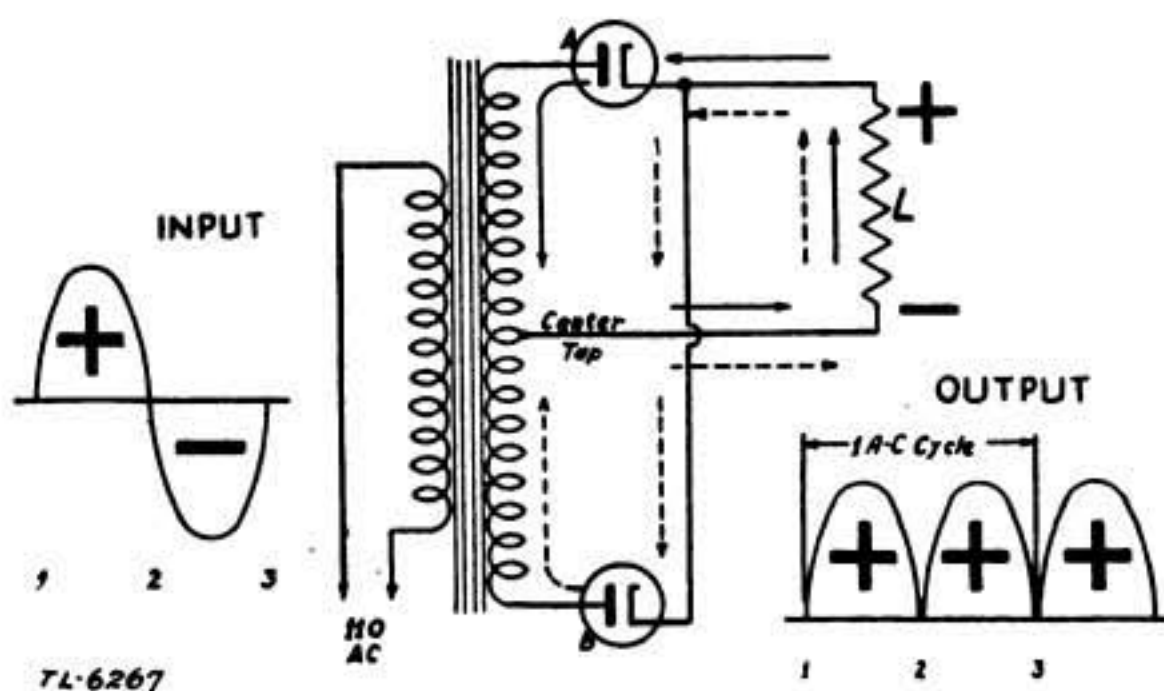


Figure 137 Full-wave rectifier.

ring to figure 137, assume that during the first alternation the plate of tube A is positive with respect to the center tap of the transformer. Since the plate of this tube is positive, electrons will flow as indicated by the solid arrows. During the next alternation the voltage across the secondary winding of the transformer will be reversed, thus making the plate of tube B positive with respect to the center tap, and the plate of tube A negative. No current will flow through tube A because the plate is now negative. The plate of tube B is positive, however, and electrons again will flow through load resistor L . Electron flow during the negative alternation is represented by the dotted arrows. It should be noted that current through resistor L is always in the same direction. Observe also that there are two d-c pulsations for each a-c cycle, one for the positive alternation and one for the negative alternation. Thus it may be seen that both alternations are combined and that the output pulsations of a full-wave rectifier are twice the frequency of the input power. This results in lower filter requirements. For relatively low voltages, such as those required in receivers, the full-wave rectifier may consist of two plates and a filament or cathode in one envelope. For the higher voltages required in transmitters, two separate tubes are usually used.

c. Vacuum-tube rectifiers are of two general types, *high-vacuum* and *mercury-vapor* tubes. The former offers the advantage of ruggedness, the latter, high efficiency. Both tubes contain two elements, a plate and a cathode, and both operate on the principle of current flow only during intervals of positive plate potential. *High-vacuum diodes* are employed as rectifiers for power supplies of radio receivers and low-powered stages of transmitters. The voltage drop across this type of rectifier is proportional to the current drawn through the tube, and is fairly high in comparison to some other types. The mercury-vapor rectifier tube is of greatest value where high voltage and large current are to be handled. The voltage drop across a mercury-vapor tube is extremely low, being approximately 15 volts regardless of the current drawn by the load.

89. Power Supply Filters

a. The output of vacuum-tube rectifier systems is made up of pulsations of current and voltage, all in the same (positive) direction. Before this rectified voltage can be applied to the plate or grid circuits, it must be smoothed out into a steady, nonfluctuating d-c flow. Such smoothing out of the pulsations is accomplished by means of filter circuits, which are electric networks consisting of series inductors and shunt capacitors. Filter circuits may be classified as capacitor-input or choke-input filters, depending on whether the filter input consists of a shunt capacitor or a series inductor (choke coil). Figure 138① shows a filter of the capacitor-input type; figure 138② shows a choke-

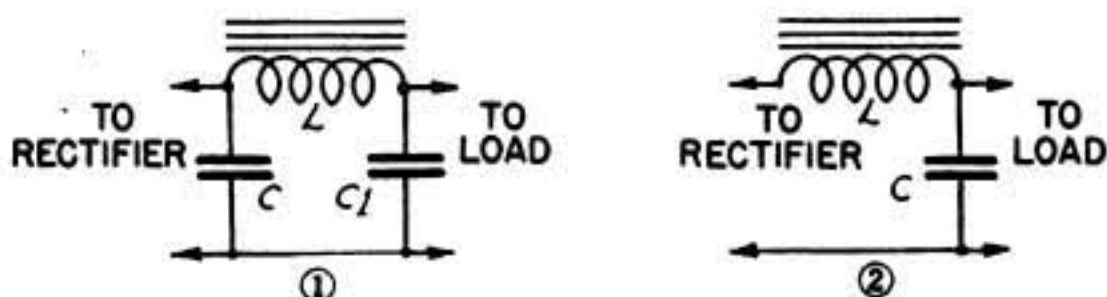


Figure 138. Types of filter networks.

input type. A resistance load connected to the output of a full-wave rectifier is shown in figure 139①. The voltage across the load will follow the rectified a-c pulsations as shown in figure 139②. This is the condition for a rectifier *without a filter network*.

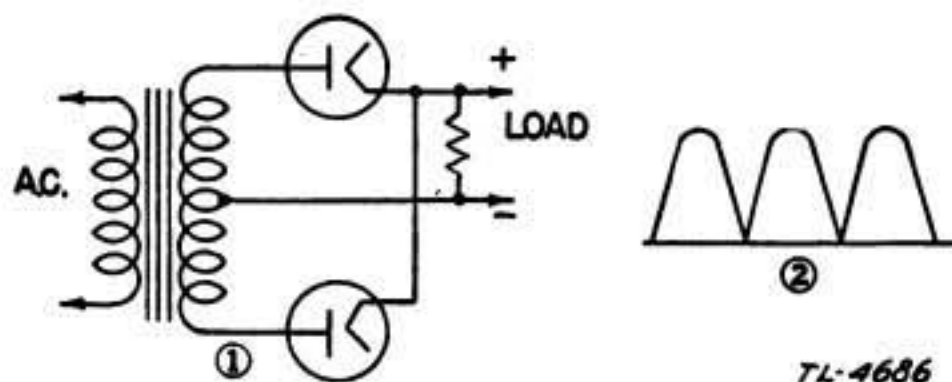
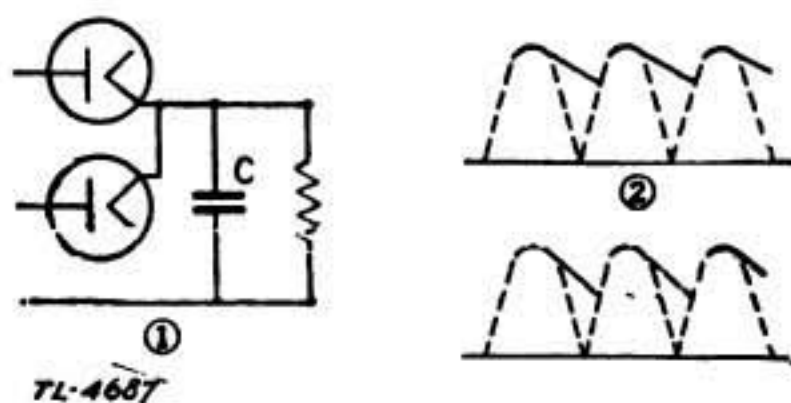


Figure 139. Load connected across output of a full-wave rectifier, and current waveform through the load.

b. The capacitor-input filter (fig. 140①) is the simplest type of filter and consists of a single capacitor, C , connected across the rectifier output and in parallel with the load. During the time the rectified alternating current is approaching its peak value, it is charging the capacitor and delivering a current to the load. After reaching the



- ① Rectifier with capacitor filter.
 ② Voltage across C with small load current.
 ③ Voltage across C with large load current.

Figure 140. A capacitor filter and output waveforms with small and large loads.

peak voltage, the output of the rectifier begins to decrease until the alternation is completed. During this decrease in applied voltage, the capacitor has a higher voltage than the rectifier-output voltage. As the capacitor cannot discharge back through the rectifier tube, it must release its energy through the load. The values of the capacitor and the applied voltage determine the amount which the capacitor can store. If the load current is small, the capacitor will discharge slowly. (See fig. 140②.) A large load current will cause the capacitor to discharge more rapidly. (See fig. 140③.) This filter, while eliminating some of the ripple voltage from the output of the rectifier system, has several disadvantages. The amount of ripple voltage remaining in the output is greater than can be tolerated in the plate supplies of receivers, amplifiers, and radiotelephone transmitting equipment. Another disadvantage of the capacitor-input type of filter is the heavy current drawn through the rectifier tube. While the capacitor is charging, it draws a current several times that drawn by the load. This charging current plus the load current may be great enough to cause damage to the rectifier tube. The capacitor-input system is not advisable when using the mercury-vapor rectifier tube at high voltages, because the heavy rush of current which charges the capacitor may damage the cathode.

c. A series choke may be added to the simple capacitor filter of figure 140① with an appreciable improvement in the filtering action. Such a capacitor-input filter is shown in figure 141. The inductor, or choke coil, has an iron core, and may be from 10 to 45 henrys in value. Care must be exercised when replacing choke coils in faulty power supplies. A choke coil designed for use on the negative side of the filter system is

not sufficiently insulated to withstand the high voltages which exist between the positive side and ground. Since the entire load current flows through this choke, it should have small resistance to direct current. The choke coil offers high opposition to the pulsations in the current. This property of coil L produces a smoothing effect upon the rectified output, and when combined with shunt capacitor C , an additive smoothing effect is produced. The action of the capacitor when used with the choke is similar to that of the single capacitor filter: capacitor C charges during the increase in voltage until the peak is reached, and the current begins to flow through L to the load at the same time.

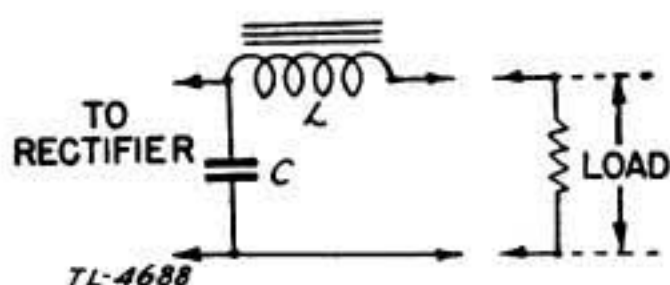
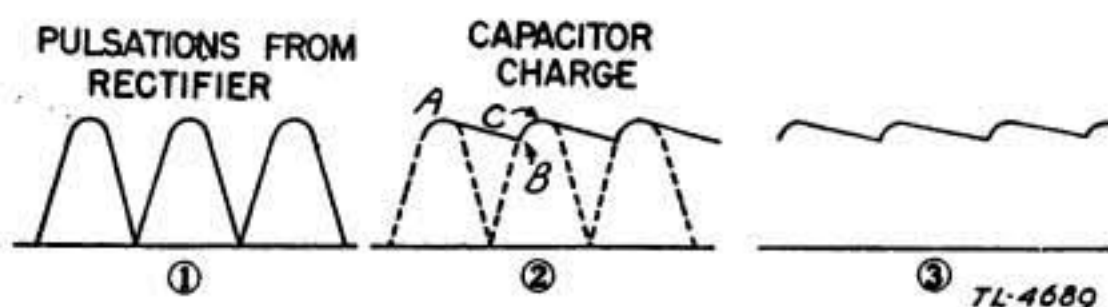


Figure 141. A simple capacitor filter with choke coil.

But the inductance of choke coil L prevents any rapid change in the current flowing to the load and thus helps capacitor C to store energy until the next charge. The complete action of this type of filter is shown in figure 142. The capacitor has become fully charged at A of figure



- ① Rectifier output.
- ② Capacitor charge and discharge cycle.
- ③ Waveform of filter output.

Figure 142. Waveforms of filter shown in figure 141.

142② and the input voltage is beginning to decrease. The choke, by its inductive action, opposes any decrease in the load current, and the capacitor, being charged to a higher voltage than the applied voltage, begins to discharge slowly through the coil. But before the capacitor has lost much of its charge, it begins to receive another charge from the next impulse, as shown at B of figure 142②. The capacitor receives energy from the rectifier during the time interval from B to C (fig. 142②), again becoming charged to approximately the peak voltage of the rectified wave. The action of the choke and capacitor for the second alternation of the wave is the same as for the first, and this is repeated for every half-cycle. The output voltage waveform applied to the load is shown in figure 142③.

d. The addition of a second shunt capacitor C_1 across the capacitor-input filter, as shown in figure 143, lowers the ripple output voltage below that of figure 142③. This network, consisting of one choke coil

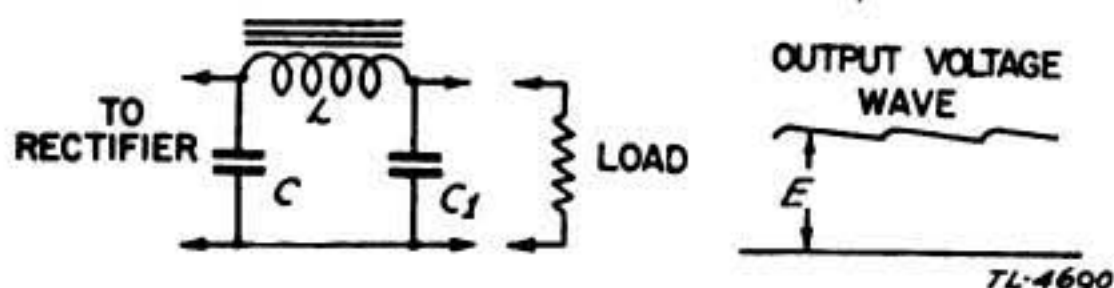


Figure 143. Circuit of a complete capacitor-input filter and waveform of the output.

and two shunt capacitors, is considered one filter section. If a more elaborate system is desired, another section may be added, as shown

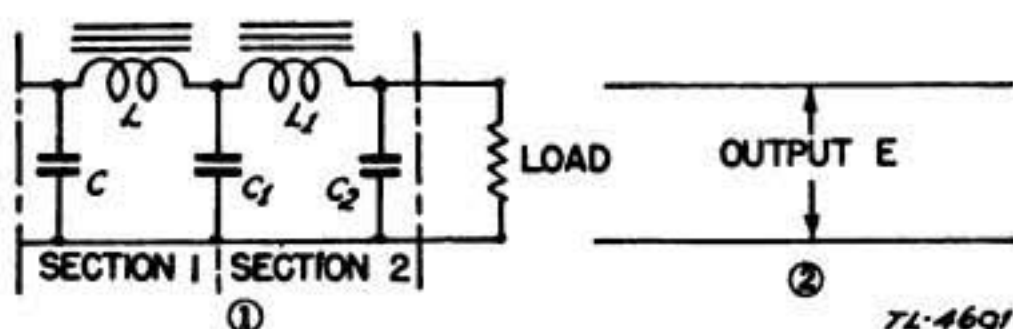


Figure 144. Two-section capacitor-input filter and output waveform.

in figure 144, considerably improving the output voltage to an almost steady condition.

e. The choke-input type of filter, like the capacitor-input filter, may have several different forms. A simple choke-input filter, consisting of a single inductor, is shown in figure 145. The output voltage waveform (across the load) for a given rectifier waveform, is also shown in figure 145. The choke coil offers a high reactance, or opposition, to any

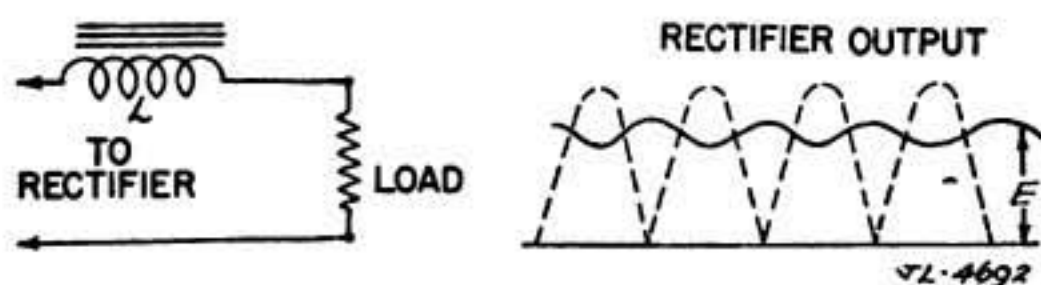


Figure 145. Choke-input filter and output waveform.

change in the current flowing through it. The filter-input voltage increases from zero at the beginning of the input alternation, but the current builds up more slowly than in capacitor-input systems. The coil smooths out some of the ripple voltage by opposing any sudden increase in current flowing through it, and acts to keep the current at a steady value when the output from the rectifier begins to decrease. The coil likewise delays the decrease in current until the second alternation from the rectifier again begins to supply energy to the circuit. The same process is repeated for each succeeding alternation.

f. A single capacitor added to the simple choke-input filter of figure 145, will eliminate more of the ripple from the filter output. The capacitor is placed across the output in parallel with the load, and is known as a single-section choke-input filter. The circuit of a single-

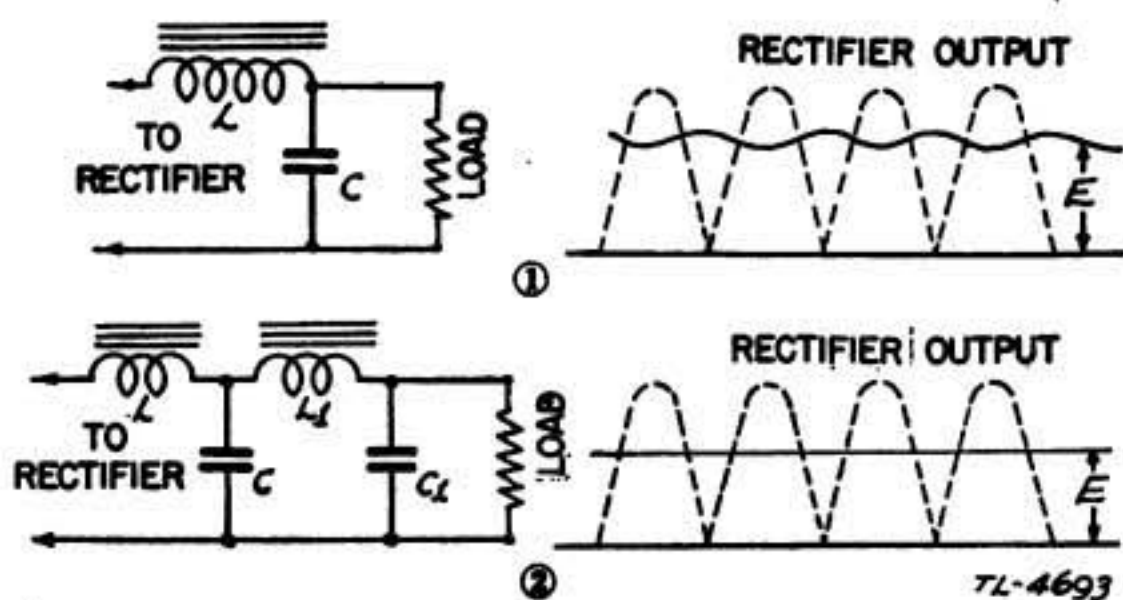


Figure 146 Single-section and two-section choke-input filters, showing input and output waveforms.

section filter is shown in figure 146(1), with the voltage output wave (across the load) for a given waveform from the rectifier. A two-section filter, with similar waveforms is shown in figure 146(2).

g. The capacitor-input and inductor-input filters have been shown to have about the same effect upon the ripple component of the rectifier-output wave. However, they possess quite different characteristics in another respect. The first capacitor of the capacitor-input filter system is charged to approximately the peak voltage of the rectified alternating current and does not completely discharge between alternations or pulsations. The capacitor remains charged very near to this peak voltage, thereby keeping the output voltage of the filter system at a value comparable to its peak input voltage. For small load currents, the voltage output from the filter will approximate the peak voltage of the rectified alternating current. However, the output voltage drops off rapidly as the load current increases. A capacitor-input filter will give satisfactory service only in applications where the load conditions are reasonably constant, such as a class *A* amplifier, where the average value of current drawn from the power supply does not vary. The output voltage from a power supply using a choke-input filter will be approximately equal to the average value of the rectified a-c voltage. This type of filter finds its greatest use where constant voltage must be maintained under varying load conditions, as is the case with class *B* amplifiers.

90. Bleeders

In most power supply units, the rectifier tube is of the filament type which begins to pass current immediately after it is turned on. The

tubes used in receivers and amplifiers, however, are usually of the indirectly heated type, and do not begin operating as soon as the high voltage is applied. A bleeder resistor places a load on the power supply immediately, thus preventing any high-voltage surge through the unit. In transmitter power supplies, the bleeder serves as a device to maintain a more constant voltage when the transmitter is keyed. The bleeder also serves to discharge the capacitors in the power supply after it has been shut off, thus eliminating any danger of a high-voltage shock to the operator, should he have occasion to repair the equipment.

91. Voltage Dividers

a. The various tubes and the different tube elements require different voltages, which may be obtained by means of a voltage divider connected across the output terminals of the filter. This voltage divider also serves as a bleeder resistor, with the bleeder current usually averaging between 10 and 15 per cent of the total current drawn from the power supply. The currents flowing through the resistor and the value of resistance between the taps determine the division of voltage along the voltage divider. The voltage and current requirements for the load must be determined before the power supply and voltage divider can be designed. Any change in the load current drawn from any particular tap on the voltage divider will affect the voltage distribution of the entire voltage-dividing system.

b. A voltage-divider system typical of those used in modern receivers is shown in figure 147. The voltage divider is connected across the output terminals, *A* and *E*, of the capacitor-input filter, with taps at *B*, *C*, and *D* properly located to provide the voltages shown in the diagram. The taps *A*, *B*, and *C* are at a positive voltage with respect

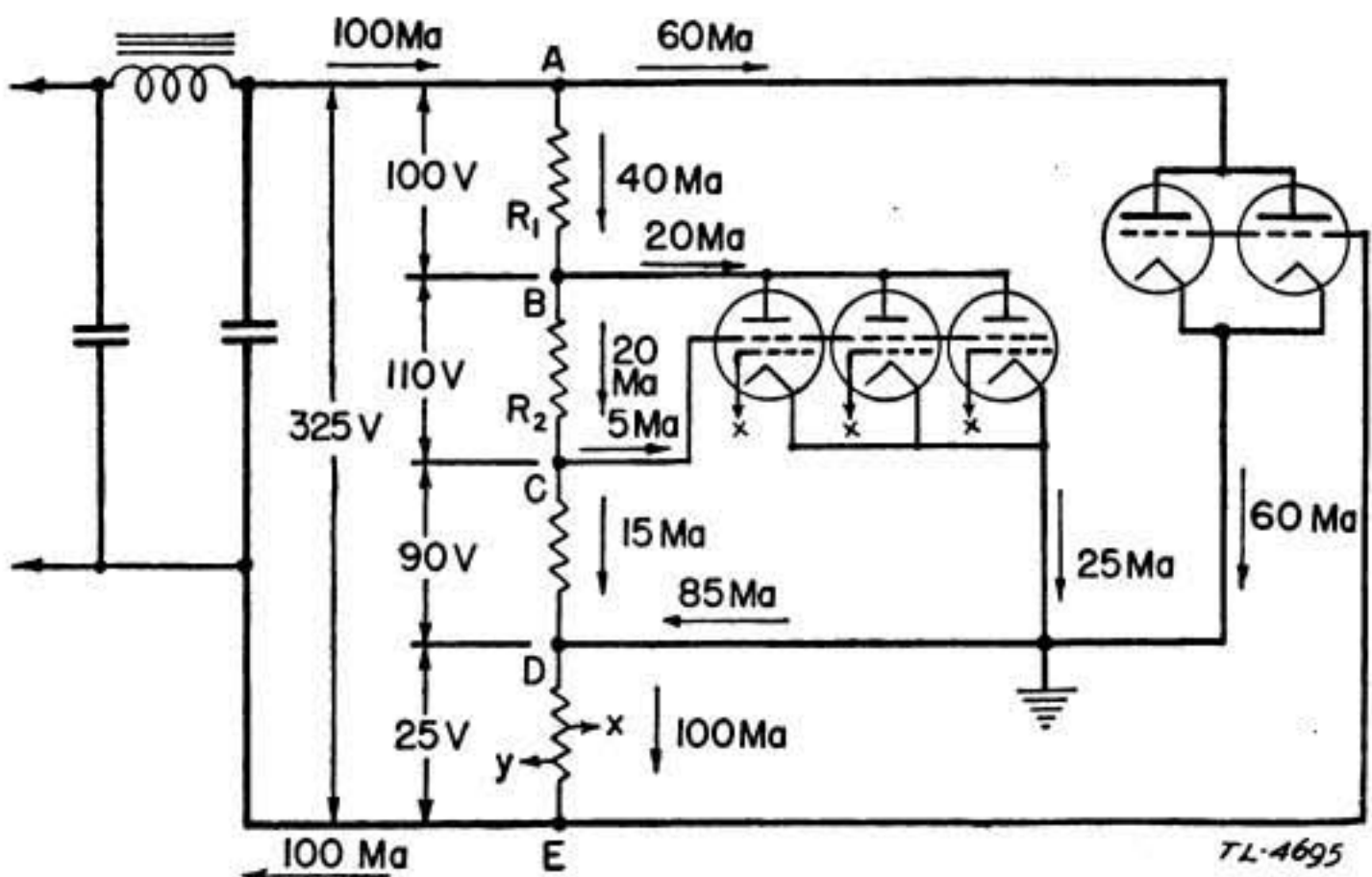


Figure 147. Voltage-divider circuit for radio receiver.

to tap *D*, which is grounded. The terminal at *E* is negative with respect to *D*, and any tap along the resistor between *D* and *E* will be negative with respect to ground. In this instance the maximum plate voltage required is 300 volts for the power-output tubes, and the maximum negative voltage is 25 volts for bias to the grids of these tubes. The total voltage of the power supply must therefore be 325 volts. The total current drain for all tubes in this case is 85 milliamperes. To this must be added the bleeder drain 15 milliamperes, making a total current of 100 milliamperes required from the power supply. Figure 147 shows this total of 100 milliamperes flowing from the filter to point *A* of the voltage divider, where it then divides: 60 milliamperes go to the plate circuit of the output tubes, and the remaining 40 milliamperes pass through the resistor R_1 , to point *B*. The voltage drop across R_1 , which is necessary to decrease the filter-output voltage to 200 volts for the plates of the amplifier tubes, must be 100 volts. Hence, to calculate the value of R_1 , divide the required drop (100) by the current flowing through R_1 , which in this instance is 40 milliamperes. Thus R_1 establishes a voltage of 200 volts between points *B* and *D* on the voltage divider. By Ohm's law:

$$R_1 = \frac{E}{I} \text{ or } \frac{100}{.040} = 2,500 \text{ ohms}$$

At *B* the current divides, so that 20 milliamperes is delivered to the amplifier tubes and 20 milliamperes continue through resistor R_2 to terminal *C*. The resistor R_2 must decrease the voltage from 200 to 90 volts with 20 milliamperes flowing through it. This is a voltage drop of 110 volts and by Ohm's law it is found to be 5,500 ohms. At *C* the current drain again divides, so that 5 milliamperes is delivered to the screen grid and the oscillator plate circuit. The remaining 15 milliamperes, which is the bleeder current, passes from *C* to *D*, causing a voltage drop of 90 volts between *C* and the grounded tap *D*. The resistance of the resistor between *C* and *D*, again calculated by Ohm's law, is 6,000 ohms. Bias for the r-f and a-f amplifier tubes may be obtained from taps *X* and *Y* properly located between *D* and *E*, or by resistors in series with the cathode circuits. Power dissipation for each resistor may be calculated by the formulas I^2R or EI . The latter formula is preferable in this particular example, since the voltage across each resistor has already been established. The resistors used should be of proper wattage rating to carry safely whatever current must flow through them, without undue rise in temperature. It has been found that resistors maintain their values and have longer life if they are worked at about 50 percent of their rated power-carrying capacity. The power expanded in resistor R_1 is 4 watts; therefore, it should have a rating of 8 watts to conform to the rule given above. A 10-watt resistor is the closest stock size to this value and is thus the logical choice.

92. Electro-mechanical Power Supplies

Electro-mechanical power equipment includes motor generators, gasoline engine driven generators, hand-driven generators, dynamotors, and vibrator systems. (All of these electro-mechanical power supplies, with the exception of dynamotors and vibrators, are discussed in TM 1-455.) Dynamotors and vibrators are used in radio power circuits where it is necessary to convert a low d-c voltage (such as might be supplied by the ignition battery of a truck, tank, or airplane) to the higher voltages required for receiver and transmitter operation.

93. Dynamotors

a. A dynamotor is used to change a low d-c voltage to a high d-c voltage, thereby fulfilling the requirements of radio receivers and transmitters. It is essentially a motor and a generator mounted, or wound, on a common frame. A single field winding is used to provide the magnetic field for both driving and generating purposes. The armature consists of two windings, both of which are wound on the same armature core, but connected to separate commutators. One winding serves to produce the driving force when energized by a low d-c voltage. The other winding generates a high voltage when rotated within the magnetic field.

b. The functional characteristics of a dynamotor are shown in figure 148. The heavy line indicates the low-voltage motor circuit. Current from the battery flows through the field coils and the motor winding of the armature, setting up a magnetic field around both. These magnetic fields oppose each other and cause the armature to rotate.

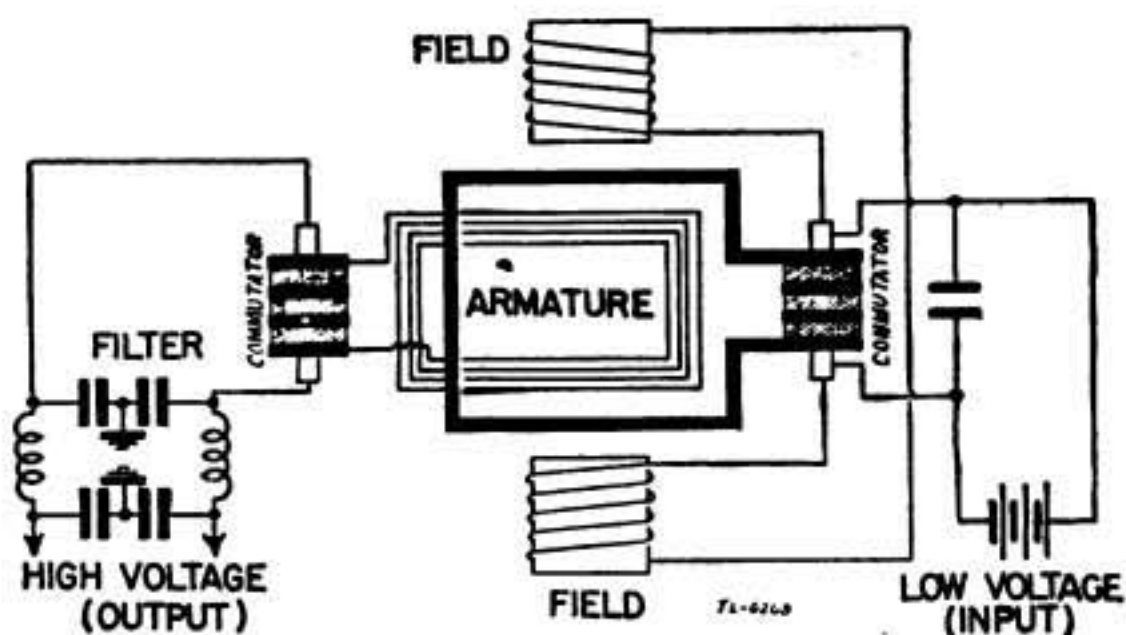


Figure 148. Functional diagram of a dynamotor.

Since the armature and field windings are in parallel this is called a *shunt-wound* motor. With this type of winding the speed of the motor remains fairly constant with changes in the load placed upon it by the generator. The high-voltage winding, represented by the finer lines between the fields (fig. 148) is wound on the same armature so

that it will rotate with the motor winding. When turning, it cuts the lines of force of the common field and generates a voltage which is collected by the brushes at the high-voltage commutator. The greater the number of turns in the high-voltage armature winding the greater will be the voltage output.

c. Filters are placed in the high-voltage leads to filter out high-frequency currents produced by sparking between the brushes and the commutator segments, so that it does not cause interference with radio reception. The filter consists of a combination of r-f chokes and capacitors. The purpose of the chokes is to prevent circulation of the r-f energy through the external wiring. The capacitors bypass this energy to ground. Some additional audio filtering must also be provided to eliminate commutator ripple. This will usually consist of a series inductor of comparatively high value, and a shunt capacitor. Functional characteristics of the audio filter are similar to filtering action discussed under a-c power supplies.

d. The circuit diagram of a typical dynamotor power supply is shown in figure 149. Filter 1 is an r-f unit to eliminate any r-f energy in the

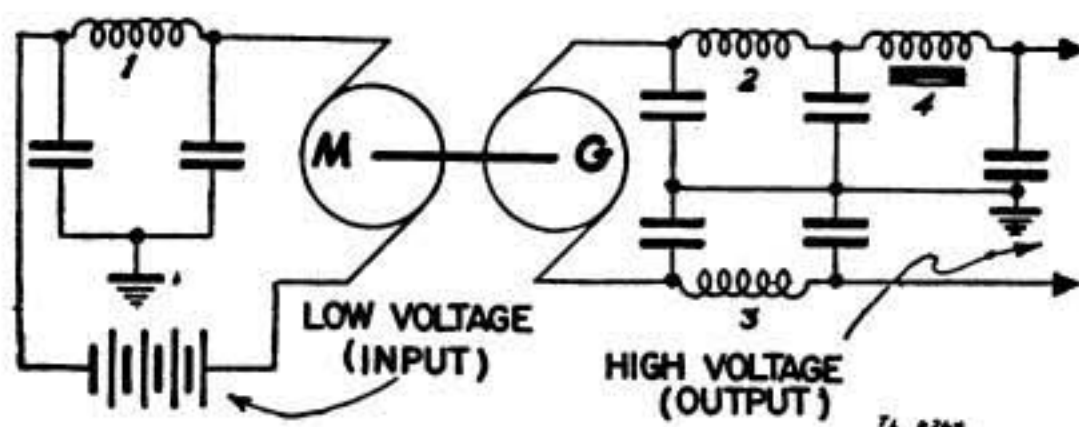


Figure 149. Diagram of dynamotor power supply and filter networks.

low-voltage circuit. *M* is the motor section of the dynamotor and is connected to the battery, which provides driving power. *G* is the generator side of the dynamotor and the output from this unit is fed through the choke coils 2, 3, and 4. Chokes 2 and 3 are r-f choke coils; choke 4 is an iron-core coil. In combination with the capacitors across the line, these chokes serve to prevent radiation of r-f energy and to reduce commutator ripple in the output voltage.

e. The maintenance of dynamotors is important to their efficient operation.

(1) If a dynamotor stops, there may be an open circuit in the motor armature, or the field. As a first step, fuses should be checked in the low-voltage supply circuit.

(2) If the dynamotor runs but no high voltage is present, the trouble is in the generator section of the armature. Fuses in the high-voltage circuit should be checked.

(3) Brushes and commutators may cause trouble if oil or dirt collect on them. Worn brushes should be replaced.