RADIO TUBES AND ANTENNAS

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Radio Tubes and Antennas

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RADIO ANTENNAS

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RADIO TUBES

UNDAMPED-WAVE RADIO COMMUNICATION

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Published by

INTERNATIONAL TEXTBOOK COMPANY

SCRANTON, PA.

INTERNATIONAL TEXTBOOK PRESS
SCRANTON, PA.

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NOTE.—This book is made up of separate parts, or sections, as indicated by their titles, and the page numbers of each usually begin with 1. In this list of contents the titles of the parts are given in the order in which they appear in the book, and under each title is a full synopsis of the subjects treated.

RADIO ANTENNAS

RADIO TUBES

UNDAMPED-WAVE RADIO COMMUNICATION

RADIO ANTENNAS

Serial 2474 Edition 1

ANTENNAS AND RADIATION

PRINCIPLES OF TRANSMISSION

MAGNETIC AND ELECTRIC FIELDS

1. The function of an antenna is to radiate or collect the high-frequency energy used for radio communication. The simple antenna may be considered as a doublet, as shown in Fig. 1. Here a source of high-frequency energy, such as an alternator *a*, is connected to a vertical wire *b* extended upwards, and a similar wire *c* extended downwards. The two wires *b* and *c* have capacity between them and may be considered as the plates of a condenser with an air dielectric.

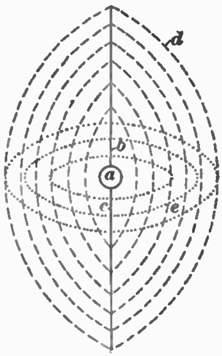


FIG. 1

Suppose the alternator *a* is just starting on a positive cycle and charges the wire *b* positive and the wire *c* negative. An electric strain is set up in the space about the antenna, which may be represented by imaginary electrostatic lines of force *d* extending from one wire to the other. These lines of force immediately start to move away from the antenna with the velocity of light. In the meantime, the alternator voltage advances to the peak of its positive cycle, at which time the electrostatic lines of force reach a maximum value. These lines of force represent stored energy, just as a stretched spring represents stored energy. As soon as the alternator voltage starts to decrease, the electrostatic lines of force begin to collapse back onto the antenna, giving up their energy, which reappears in the form of a magnetic field set up by the current in the antenna. This electro-magnetic field may be represented by imaginary lines of force *e* at right angles to the electrostatic lines of force.

2. Before all of the electrostatic field has had time to return to the antenna, the alternator *a*, Fig. 1, starts on its negative cycle, charging the wire *b* negative, and the wire *c* positive, thereby setting up a field that is opposite to what it was before, making it impossible for the remaining portion of the returning electrostatic field to give up its energy to the antenna. This portion of the electrostatic field never returns to the antenna, but travels away from the antenna with the velocity of light as a free wave. This action takes place on every half cycle of the alternator, and continues as long as the alternator voltage is applied to the antenna.

RADIATION AND INDUCTION FIELDS

3. The field about the antenna can be considered as having two portions, one portion that builds up and collapses on the antenna itself, and a second portion that becomes detached from the antenna, never to return. The first portion is called the *induction field*, and the second portion is called the *radiation field*. It is the radiation field that is useful in radio communication.

It can be shown, mathematically, that the induction field and the radiation field have very definite proportions at any given distance from the antenna. The induction field falls off as the square of the distance from the antenna, whereas the radiation field falls off directly as the first power of the distance. At a distance of one wavelength from the antenna, the induction field is small compared with the radiation field, and its effect may be neglected.

4. Aside from absorption of energy by the earth, the total energy in the radiated wave remains constant. Hence, as the wave advances, the energy becomes spread out over a greater area, and the energy at any point decreases directly as the distance increases. The decrease in amplitude of the radiated wave is analogous to the decrease in amplitude of a water wave produced by throwing a stone into a smooth mill pond. The water wave has a large amplitude at first, but the amplitude becomes smaller and smaller as the wave expands in ever-widening circles, because the original energy of the impact of the stone spreads out over a large area.

The traveling radiation field has two components, the electrostatic field and the electromagnetic field, the energy in these two fields being equal. The form of these two fields will be considered later in connection with an antenna with an earth connection in place of the lower half of the doublet.

FREQUENCY AND WAVELENGTH

5. There is a definite relation between the frequency of the alternator or other transmitter and the wavelength. While the transmitter passes through one complete cycle, the radiated wave travels a distance of one wavelength. Since the radiated wave travels with the velocity of light, it will travel 186,000 miles, approximately, or 300,000,000 meters in one second. When the frequency of the transmitter is known, the distance the wave will travel during one cycle, or the wavelength, may be calculated by the formula

$$\lambda = \frac{V}{f} = \frac{300,000,000}{f} \text{ meters}$$

in which λ = wavelength, in meters (λ is the Greek letter *lambda*);

V = velocity of electromagnetic waves, in meters per second;

f = frequency, in cycles.

6. The foregoing formula may be used for calculating the frequency from the wavelength, and vice versa. For example, 1,000,000 cycles per second would correspond to a wavelength of 300 meters; 100,000 cycles would correspond with a wavelength of 3,000 meters, etc.

When the radiated wave reaches the receiving antenna, it induces in the antenna a voltage having the same frequency as the transmitter. This induced voltage causes a current in the antenna, and this current will be a maximum if the antenna is tuned to resonance for that particular frequency. Some of the energy is transferred to the receiving set, where it is detected and amplified and operates the telephones, loud speaker, or other device attached to the output of the receiver.

ANTENNA AND GROUND

7. The simple doublet of Fig. 1 is rarely used except at extremely high frequencies or short wavelengths, where the wires of the doublet are only a few meters long. On long wavelengths, a doublet suitable for radiating considerable amounts of power would be very high, and it would be very expensive to provide towers high enough to support it.

To overcome this difficulty, the lower half of the doublet is usually omitted, and an earth connection is substituted. The capacity effect then exists between the antenna and the earth. The distribution of the electrostatic lines of force from a grounded antenna is as shown in Fig. 2. This figure also shows the probable shape of the electrostatic field after the lines of force have become detached from the antenna and are traveling as free waves. At the instant shown, the antenna is assumed to be charged at a maximum positive voltage. The distance from the antenna to the center of the positive traveling wave, shown as λ, is one wavelength, since this positive traveling wave was radiated by the preceding positive cycle of the transmitter. The electromagnetic lines of force are not shown, but they are traveling parallel to the surface of the earth in ever-widening circles, with the antenna as a center, analogous to water waves traveling from the center of disturbance when a stone is dropped into still water.

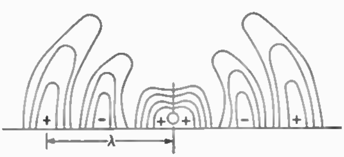


FIG. 2

TYPES OF ANTENNAS

INVERTED L ANTENNA

8. The amount of power that can be put into an antenna is often limited by the voltage built up on the antenna, particularly at the longer wavelengths. In order to keep this voltage down to the limits of practical insulation, it is often necessary to increase the capacity of the antenna by adding a flat-top, or horizontal, portion. The addition of a flat-top portion also has the important effect of increasing the effective height, so that, for towers of a given height, the antenna becomes more effective both as a radiator and as a receiving antenna.

There are many types of antennas, but nearly all of them are simply modifications of the idea of combining a flat-top portion with a vertical portion, or *lead-in*, as the vertical portion is usually called.

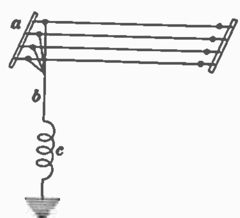


FIG. 3

9. Perhaps the most common form of antenna is the *inverted* L type shown in Fig. 3. The horizontal or flat-top portion is shown at *a*, whereas the lead-in, or vertical portion, is shown at *b*. The antenna is tuned by the inductance *c*.

If the flat-top portion is long compared with the vertical height, the inverted L antenna is somewhat directional, with maximum transmission and reception in the direction opposite the free end, that is, from the left in Fig. 3. This directive effect is not clearly understood, but in ordinary antennas it is relatively small, and it may be neglected entirely if the horizontal length *a* is not much greater than the vertical height *b*. In some cases, the horizontal length is over ten times the vertical height, and, in such cases, appreciable directive effect is noted, as, for example, in the case of the Marconi bent antenna, which is a form of the inverted L antenna, with a very long horizontal portion.

T-TYPE ANTENNA

10. The T-type antenna is similar to the inverted L type except that the lead-in is brought down from the center, rather than from one end. The T-type antenna is practically non-directional. It is used frequently on ships, where the radio room is in the center of the ship.

MULTIPLE-TUNED ANTENNA

11. The Alexanderson multiple-tuned antenna is a special arrangement making it possible to use a very long horizontal portion efficiently. It is equivalent to operating several antennas in parallel. In Fig. 4, leads are shown

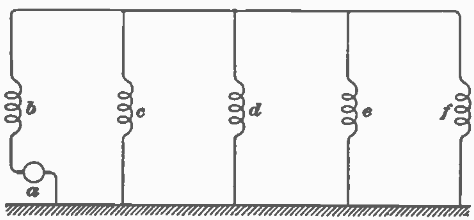


FIG. 4

coming down from several points in the antenna to suitable tuning coils connected to earth. The alternator *a* feeds energy at only one down lead, such as at *b*. Each section *b*, *c*, *d*, *e*, and *f* is tuned separately in such a manner that all of the currents in the vertical portions are in phase, or pass through corresponding values during the same instant, so that the total antenna current is the sum of the currents in all the down leads. A typical antenna of this type is 1.25 miles long and 400 feet high, operating at wavelengths from 11,000 to 20,000 meters, for transoceanic telegraph service. The multiple-tuned antenna is rarely used as a receiving antenna, but is one of the most important types of transmitting antennas.

UMBRELLA ANTENNA

12. The name of the umbrella-type antenna is quite descriptive of its construction, as it consists of a high center support, Fig. 5, with wires extending radially from it like the ribs of an umbrella. The antenna wires are insulated from the earth and from the central mast, and are connected together at the top and to the lead-in *a*. The receiving or transmitting system is connected at *b*. The antenna wires also act as guys to support the pole.

If the lower ends of the wires come too close to the ground, the field will be confined in the space between the lead-in and

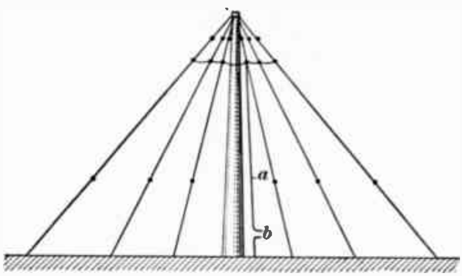


FIG. 5

the wires, and there will be very little radiation. The wires should not make an angle of less than 50 or 60 degrees with the mast, and the lower ends should be insulated at some distance from the ground, so that the lower ends of the wires are half the mast height or more from the ground.

The umbrella-type antenna is frequently used for portable stations and is also sometimes used in long-wave transmitting stations, where twenty or more wires are spaced equally about the mast, with the lower ends supported on shorter masts, in some cases. It has the advantage of being non-directional and gives a considerable amount of capacity and effective height with a single high mast, which is a considerable factor, as high masts are very expensive.

CONDENSER ANTENNA

13. For measuring work, or in cases where it is desirable to calculate the effective height of the antenna, a condenser-type antenna is sometimes used. This usually consists of two large metal plates or screens, with relatively small vertical separation. If the separation is small compared with the dimensions of the plates, the effective height is very nearly equal to the separation between the plates. Furthermore, since the antenna is practically an efficient air condenser, the dielectric losses are very low and considerable energy can be radiated, in spite of the low effective height.

GROUND ANTENNA

14. There are other types of antennas more particularly adapted to reception than to transmission. Many types of ground antennas come under this classification. Owing to losses in the earth, waves arriving from a distance are tilted forward slightly, and therefore have a small horizontal component of energy, which will induce voltages in a horizontal conductor, practically independent of the vertical distance of the horizontal conductor above ground. If the horizontal length is over a quarter of a wavelength, this type of antenna becomes considerably directive; that is, it receives better from stations toward which it points than from stations that are off to one side.

15. Insulated wires lying on the ground, buried in the ground, or laid in shoal water, have been used by different investigators, notably Commander A. H. Taylor and Mr. Rogers. The voltage induced in these wires by the horizontal component of the wave, is practically independent of the distance the wire is suspended above ground, as was previously mentioned, but, if the wire is suspended at some distance above ground, it will have vertical antenna effects superimposed upon the horizontal antenna effects. The magnitude of the horizontal component depends on the wavelength and the conductivity of the ground, whereas the vertical antenna effect is dependent only on the height of the wire above ground. The horizontal component varies from practically zero over deep-sea water to perhaps 10 per cent. of the vertical component over dry sand. Hence, to operate only on the horizontal component of the wave, a ground antenna should be one hundred or more times longer than its vertical height.

The length of insulated ground wire that can be used is limited by the low velocity of the currents in the wire, which is on the order of half of the velocity of light or less. For this reason, it is usually best to use bare wires supported a short distance above the ground, as this increases the velocity and makes it possible to use a longer wire. On the other hand, where space is a consideration, it is probable that a buried ground wire will give greater directivity for the same length than a bare wire suspended above the earth.

WAVE ANTENNA

16. The *wave antenna* is a special form of directive horizontal antenna, which operates on the horizontal component of the wave, similar to a ground wire. It derives its name from the fact that it is usually about one wavelength long, this length having been found best from practical considerations. In its simple form, the wave antenna is simply a long wire suspended a few feet above the ground on poles.

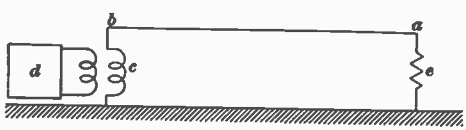


FIG. 6

A wave traveling from the right reaches end *a*, Fig. 6, first, and, owing to the wave tilt, a voltage is induced in the wire at *a*. As the wave travels along the wire from *a* to *b*, the voltage induced at *a* travels along in the wire at practically the same velocity as the wave in space, that is, the velocity of light. In like manner, the voltage induced at any intermediate point in the wire travels along the wire at the same speed as the wave. The result is that all of the voltages induced in the wire by the traveling wave arrive at the end *b* in phase, and, passing through the coil *c*, produce a strong signal at the terminals of the receiver *d*. This effect is analogous to producing a water wave in a long narrow trough by swinging a shovel into the water at regular intervals of time. If the shovel is dipped into the water in synchronism with the movements of the water wave in the trough, the wave builds up to a very large amplitude at the far end of the trough.

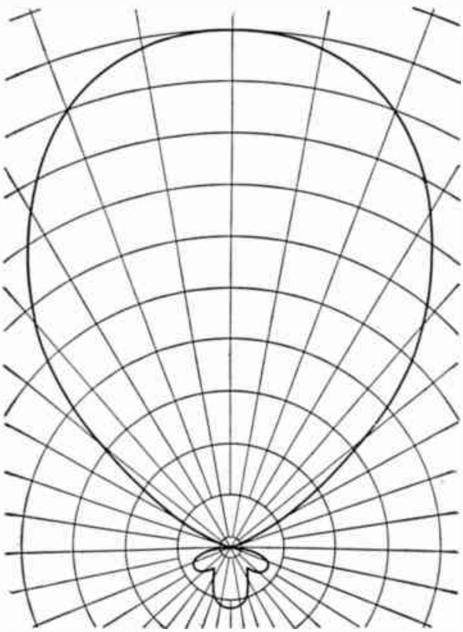


FIG. 7

17. A wave traveling from *b* to *a*, Fig. 6, builds up to a large amplitude at *a*. If the end *a* were directly grounded or left open, the energy would be reflected back to the receiver at *d*, and the antenna would be bidirectional; that is, it would receive from both directions *ab* and *ba*. By placing a resistance *e* between the antenna and ground at *a*, the energy traveling in the direction *ba* is absorbed, making the antenna unidirectional; that is, it receives only from the direction *ab*. The resistance *e* must be made equal to the *natural*, or *surge, impedance* of the wire with respect to the earth. This resistance is somewhat analogous to placing a shoaling sand surface at the end of the trough to absorb the water waves instead of allowing it to dash against a solid wall, which would reflect the wave back down the trough.

18. The unidirectional receiving properties of a horizontal wire one wavelength long, and properly damped at one end, are shown in Fig. 7. This polar diagram shows the strength of signal that would be received if a transmitting station at a considerable distance were moved around the receiving antenna in a complete circle, always keeping the same distance from the receiving antenna.

Owing to losses in the wire, the reception from the direction opposite to the direction of maximum reception is not quite zero, but it is relatively small, as shown.

The wave antenna is particularly useful for receiving from long-wave fixed stations, where the major portion of the static and interference originates from directions other than the direction of the desired signals. It is used extensively for transoceanic reception, and for long-distance reception from ships.

LOOP ANTENNA

19. The loop antenna is another form of directive antenna that is used mainly for receiving. It consists of one or more closed turns of wire, usually wound in the form of a square, as shown in Fig. 8. It may be tuned by a condenser *a* and loading coils *b* and *c*, although it is not always necessary to use loading, as the loop inductance alone is sufficient if enough turns are used. The receiver is coupled to coil *b* by means of coil *d*.

An arriving electromagnetic wave coming from the right of Fig. 8 induces a voltage in side *e* of the loop in all wires. An instant later, the same part of the wave reaches side *f*, where it induces an equal voltage in the wires of side *f*. These two voltages are exactly equal and are opposed, but there is a slight difference in phase owing to the time it took the wave to travel from *e* to *f*. Because of this slight difference in phase, there is a small resultant voltage left which causes a current in the loop. This phase difference is given by the equation

$$\phi=\frac{2\pi D}{\lambda}$$

in which ϕ = phase difference, in radians (ϕ is a Greek letter pronounced *fī*);
π = 3.1416 (π is a Greek letter pronounced *pī*);
D = distance between sides of loop, expressed in meters;
λ = wavelength, in meters.

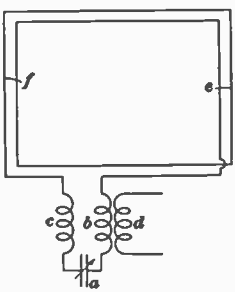


FIG. 8

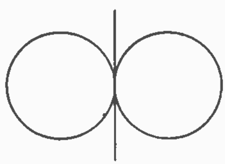


FIG. 9

20. If the signal arrives from a direction exactly at right angles to the plane of the loop, the wave reaches both sides of the loop at exactly the same instant, so there is no phase difference between the sides of the loop, and the voltages from the two sides exactly oppose, resulting in no signal. A further consideration of this subject would show that for other directions, there would be a signal of varying intensity, depending on the angle the signal makes with the plane of the loop. If a curve is plotted on polar coordinate paper, it results in the *figure 8* diagram shown in Fig. 9, which is, therefore, the directive diagram of the simple loop.

21. If the loop is made so it can be rotated on its vertical axis, it can be used to indicate the direction from which a signal is arriving. When the loop is turned until the signal is a maximum, the plane of the loop is pointing toward the transmitting station. On the other hand, if the loop is swung around until the signal disappears, the signal is coming from a transmitting station located at right angles to the plane of the loop. The zero on a properly adjusted loop can be set much closer than the maximum, because it is comparatively easy to tell where the signal disappears, but very difficult to judge slight changes in intensity near the maximum. For this reason, radio bearings are almost always taken on the minimum or zero line of the loop.

A bearing taken on the loop alone, indicates the true line of direction, but does not indicate the absolute direction, or *sense* of direction. For example, if the loop gives zero signal when its plane is East and West, it is known that the transmitting station is either directly North or directly South, but it is not possible to tell which direction is correct.

LOOP-VERTICAL ANTENNA

22. In order to get the *sense* of direction, it is necessary to make the loop unidirectional; that is, receptive from one direction, but non-receptive from the opposite direction.

This may readily be accomplished by combining the loop with a vertical antenna, as shown in Fig. 10. For the sake of simplicity, only one turn is shown on the loop, but several turns could be used. The loop is shown as *ab*, and the vertical antenna is shown as *cd*, with coil *e* in series with the vertical antenna. The coupling between coils *e* and *f* is adjusted until the voltage received from the vertical antenna is equal to the voltage received from the loop.

23. Assume an oncoming signal wave *g*, Fig. 10; this wave will progressively induce a voltage in *a*, *cd*, and *b*. All of the voltages will be in the same direction, as indicated by the small arrows. It has already been explained how the voltages in *a* and *b* do not quite neutralize, because of the phase difference between sides *a* and *b*, the voltage in side *a* being slightly in advance of the voltage in side *b*. Now suppose the loop is turned 180 degrees, or half-way around, on its vertical center line as an axis, so that side *b* is nearest the signal. Now the voltage in side *b* will be slightly in advance of the voltage in side *a*, whereas, before the loop was turned 180 degrees, the voltage in side *b* was lagging. The result is that the voltage in the loop is exactly reversed when the loop is reversed by turning it 180 degrees on its axis. On the other hand, the direction of the voltage in the vertical antenna remains the same as before. Of course, the voltages are always changing as the wave advances, but the relative phase relations between the sides of the loop and the vertical antenna always remain the same.

24. If the vertical antenna phase and intensity are properly adjusted, the loop voltage and vertical-antenna voltage will exactly balance for one position of the loop, and will add in phase if the loop is turned around 180 degrees, as this reverses the direction of the loop voltage without changing the direction of the vertical antenna voltage, as already explained. The resultant reception diagram is a *cardioid*, or heart-shaped, curve, as shown in Fig. 11 at *a*. If the vertical-antenna voltage is not as strong as the loop voltage, the loop effect predominates, resulting in the unsymmetrical curve *b*. If the vertical-antenna voltage is too strong, the vertical-antenna effect predominates, resulting in the distorted curve shown at *c*. Any of these diagrams may be rotated by turning the loop, or they may be reversed 180 degrees by reversing either the loop or vertical-antenna connections.

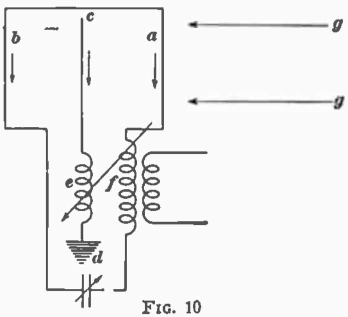


FIG. 10

DIRECTION FINDING

25. Determining Sense of Direction.—It has already been explained how the line of direction could be determined with a simple loop by swinging it until the signal disappeared, at which point the plane of the loop is perpendicular to the line of direction of the signal, and that the absolute sense of direction was not evident from the loop bearing alone, but required the addition of a vertical antenna.

This point is further illustrated in Fig. 12. Suppose the transmitter is at *a* and the loop is shown at *bc*. The signal is zero when the loop is at right angles to the line of direction *ad*, but the transmitter might be at either *a* or *d*. To determine which position is correct, the loop is swung around 90 degrees, or a quarter turn, so that the signal is received at its maximum intensity. Then the vertical antenna is switched on, as shown in Fig. 10, resulting in one of the reception diagrams of Fig. 11.

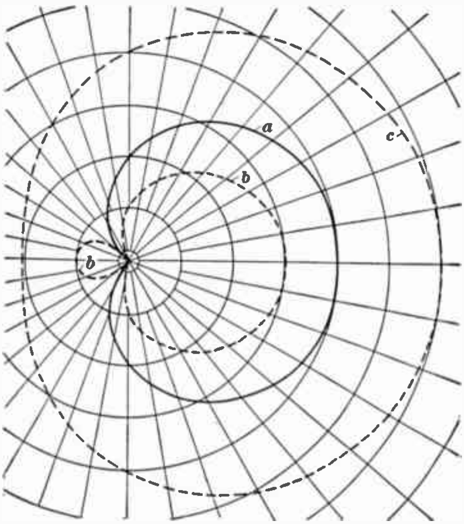


FIG. 11

26. If the transmitting station is at *a*, Fig. 13, the vertical-antenna and loop voltages may add, producing a stronger signal than the loop alone, as shown by the full-line curve, where *bc* is the position of the loop. If the transmitting station had been at *d*, the loop voltage would have opposed, resulting in no signal, or a much weaker signal when the vertical antenna was switched on. If the loop had been turned around 180 degrees, switching on the vertical antenna would have weakened the signal at *a* and strengthened the signal at *d*, now indicated by the dotted curve. Hence, when a radio compass is installed, it is necessary to check the relative direction of the loop and vertical-antenna voltages, and to mark the *sense* scale plainly, so that there can be no doubt about the proper sense of direction. Once this scale has been properly set, the loop connections should not be changed.

27. Methods of Taking Bearings.—The radio compass is a great aid to the navigation of ships and aircraft, and it is possible for them to navigate in heavy fog, or other weather of low visibility, by frequently taking radio bearings. There are two general methods for taking these radio bearings, namely:

(*a*) The ship may be equipped with a radio compass for taking bearings on fixed stations of known location.

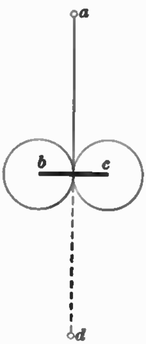


Fig. 12

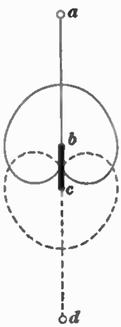


Fig. 13

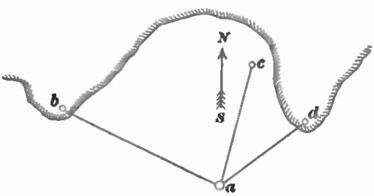


Fig. 14

(*b*) The ship may not be equipped with a radio compass installation, but has a radio transmitter. The ship sends certain identification signals, and two or more fixed land stations take radio bearings for the ship.

In Fig. 14, the ship is at *a*. Suppose the ship is equipped with a radio compass, and suppose that at points *b*, *c*, and *d* there are three land stations transmitting certain identification letters. The radio operator or navigating officer takes bearings on each of these stations, noting how many degrees East or West of North the loop bearing is by comparing with the ship's compass. The positions of the transmitting stations are marked on the chart, and the observer lays off the radio bearings on the chart. The intersection of these bearings give the ship's position at *a*.

28. If the ship has no radio compass, she calls the Master compass station, located, say, at *b*, Fig. 14, and asks for bearings. Station *b* asks the ship to send certain identification letters, and notifies stations *c* and *d* by telephone or telegraph, to take bearings on this ship. In this case, stations *c* and *d* do not transmit, but are equipped with radio-compass installations for taking bearings. As soon as stations *c* and *d* have taken their bearings, they transmit them to station *b* by wire. The operator at *b* then transmits all three bearings to the ship, where they are plotted on the chart, giving the position of the ship at *a*, as shown in Fig. 14.

By either method, two bearings would be sufficient to locate the position of the ship, but a third bearing is sometimes taken as a check. It is desirable that, for accurate results, stations *b*, *c*, and *d* should be considerably separated, so that there is a large angle between the bearings. Then, if a slight error is made in one of the bearings, it would not change the location determined for the ship appreciably.

29. Both methods are used extensively. The United States government maintains both transmitting and receiving radio-compass stations at important points along the coast. The transmitting compass stations are of relatively low power, to minimize interference, and consist mostly of automatic-spark transmitters working on a wavelength of about 1,000 meters. It has been found that the shorter wavelengths give the most accurate bearings, and also that spark, or damped-wave, transmitters give more accurate and consistent bearings than continuous-wave transmitters.

Of course, it is very simple for the ship to call the land compass station to get her bearings, but in the vicinity of a busy port, in bad weather there are so many ships requesting bearings that it is sometimes impossible for a ship to get bearings without considerable delay. The tendency, now, is for ships to have their own radio-compass installation, so they can take their bearings as frequently as they desire.

SOURCES OF ERROR IN RADIO COMPASS

30. If the signal on which a bearing is being taken is weak, static and interference may cause the signal to disappear at some distance at either side of the minimum. If the interference is steady, it is possible to determine the disappearing point on each side of the minimum, thereby locating the true minimum as half way between these disappearing points. If the interference is intermittent, it may be very difficult to take an accurate bearing. It is obvious that bearings taken at a relatively short distance, where the signal is strong, would be the most accurate.

One of the common sources of error in a radio compass is due to the vertical-antenna effect. That is, if the loop is not symmetrical with respect to earth, the loop itself may act as a vertical antenna, and if the two sides of the loop are not electrically balanced, more vertical-antenna current may pass to earth through one side of the loop than through the other side, producing a bad or displaced minimum. For example, in Fig. 10, the loading coil *f* is shown in only one side of the loop. To make the loop symmetrical to earth, a loading coil, similar to coil *f*, should be placed in series with the other side of the loop, as in Fig. 8. When this unbalanced effect is present, it either makes a very bad minimum, or else it produces a distorted figure 8 diagram similar to that shown at *b*, Fig. 11, in which case the two minimums will not come 180 degrees apart, thereby warning the operator that the bearing is not accurate. This effect is not present to any appreciable extent in a properly installed radio compass.

31. Another source of possible error is due to radiation from metal objects near the loop, particularly mast stays, other antennas, etc. In some cases, these sources of error are eliminated by breaking up the radiating system with insulators, and, in other cases, where the effect is symmetrical about the keel of the ship, the errors are corrected by the compass calibration, which is relatively simple in such cases.

Sometimes the apparent bearing of the transmitter will change. This frequently happens when the signal has to skirt along a coast line, or over shoal water, for a considerable distance. Owing to the good transmission over the sea and the poor transmission over the land, the signal tends to come over the sea route, turning the bearing toward the sea route. In some cases, errors as high as 15 to 20 degrees have been noted from this effect. This error is reduced to practically zero by placing the compass stations on points of land extending into the ocean or on small islands to keep the transmission all over sea.

32. At sunrise or sunset and during the night, bearings are sometimes erratic, owing to a phenomenon known as *night effect*. This is supposed to be a distortion of the wave front, caused by the signal arriving over two routes: (1) the regular normal path along the surface of the earth, and (2) a path that exists only at night, assumed to be a conducting medium high above the earth, known as the *heaviside layer*. If the *sky wave* arrives at a high angle, a residual voltage will be left when the loop is at right angles to the normal direction of the transmitter, resulting in a bad minimum. This effect is not noticed at short distances and can be recognized by an experienced observer by the indistinct, *mushy* sort of minimum that it produces.

Under normal conditions, a properly operating radio compass will give bearings within about 1.5 to 2 degrees on the average. Individual bearings may vary considerably more than this, but if several bearings are taken, the average should come within the limits mentioned above.

OTHER USES FOR LOOP ANTENNAS

33. The loop antenna is used frequently on broadcast receivers, where it is undesirable to put up an outside antenna. Owing to the low effective height of the loop the receiver must be very sensitive to deliver loud-speaker output, but the required sensitivity is readily attained in modern multitube receivers.

The directive property of the loop is useful for eliminating strong station interference and induction, where the source of the interference comes from a signal point more or less at right angles to the direction of the desired signal. The loop will also eliminate some static under certain conditions, but it is not nearly so effective on static as on induction and interference, because, as a rule, the static that affects broadcast waves comes from practically all directions.

For measuring signal strength, the loop is very useful, as it is easy to calculate its effective height from its physical dimensions.

ANTENNA PROPERTIES

FUNDAMENTAL WAVELENGTH

34. Wavelength of Grounded Antenna.—The fundamental wavelength of an antenna is the wavelength at which the antenna oscillates with no loading at the base. This wavelength is sometimes called the *qudrter-wave oscillation*, because the current and voltage assume a distribution in the antenna similar to one quarter of a wave.

In Fig. 15 is shown the distribution of the current and voltage in a simple vertical antenna at the fundamental wavelength, that is, without loading at the base. Curve *e* shows the voltage distribution, the voltage being zero at the base, or earth connection, and a maximum at the upper end. Curve *i* shows the current distribution, the current being a maximum at the earth connection, and zero at the upper end.

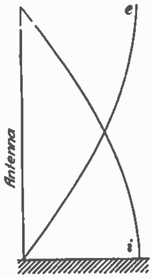


FIG. 15

35. Since the voltage and current distribution covers one quarter of a wave, it would appear that the fundamental wavelength should be four times the total length of the antenna. This would be true if the velocity of the current in the wire were the same as the velocity of the wave in space, that is, equal to the velocity of light. For a simple vertical wire, the current velocity is only slightly less than the velocity of light,

so the fundamental wave-length is 4 to 4.2 times the vertical height of the antenna.

If the antenna has a horizontal portion, the horizontal portion must be added to the length of the lead-in to calculate the fundamental wavelength. If there is more than one wire in the flat top or lead-in, the velocity of the current is lowered a certain amount, depending on the number of wires and their spacing. To calculate the fundamental wavelength of an antenna roughly, measure to total length of the antenna from the instruments to the far end of the antenna, including the lead-in and the flat-top portion. Express this length in meters (1 meter = 3.28 ft.), and multiply by 4 to 4.2 for a single-wire antenna, by 4.3 to 5 for an antenna with more than one wire, but with a narrow flat top, and multiply by 5 to 6 for an antenna with a wide flat top.

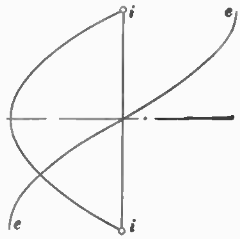


FIG. 16

36. Wavelength of Doublet.—The fundamental wavelength of a doublet is the same as of the simple vertical antenna half as long as the doublet. The reason for this is that the lower half of the doublet takes the place of the earth connection, leaving the current in the upper half of the doublet distributed the same as it was in the simple vertical antenna. The distribution of the voltage and current in the doublet is shown in Fig. 16. At the center of the doublet the voltage is zero, whereas the current is a maximum. At the ends the current is zero, whereas the voltage is a maximum. The voltage distribution, as shown by curve *e*, is at opposite potential at the two ends of the doublet.

HIGHER HARMONICS

37. Both the grounded antenna and the doublet will resonate at other frequencies higher than the fundamental For example, in Fig. 17, the distribution of the current and voltage is shown for a grounded antenna oscillating at the three-quarter wave oscillation. The current is zero at a point one-third of the distance up from the base and again at the top. The voltage is zero at the base, and again zero at a point two-thirds of the distance up from the base.

If it is kept in mind that the current must always be zero at the open end of the antenna, and that the voltage is a maximum where the current is zero, it is a simple matter to draw out the distribution of current and voltage for any mode of oscillation.

38. If the length of the simple grounded antenna is given in meters and if the velocity of the current in the antenna is assumed to be equal to the velocity of light, it can be shown that the antenna will resonate without loading at any *odd* quarter wave, that is, at $\frac{4L}{1}, \frac{4L}{3}, \frac{4L}{5}, \frac{4L}{7}$, etc., meters, in which L is the length of the antenna in meters. It can be shown that the doublet will resonate without loading at any *even* quarter wave, that is, at $\frac{4L}{2}, \frac{4L}{4}, \frac{4L}{6}, \frac{4L}{8}$, etc., meters, in which L is the total length of the doublet in meters. The even quarter-wave oscillations are more often called half-wave oscillations, since they are multiples of the half-wave.

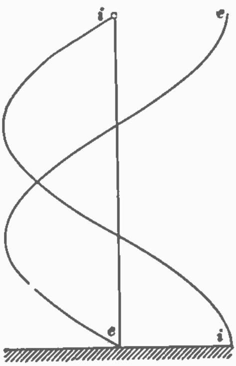


Fig. 17

These higher harmonics are not so well known as the fundamental, or quarter-wave, oscillation, as it has usually been the practice to use only the quarter-wave oscillation. However, the higher harmonics are now frequently used for transmission at very short wavelengths. The doublet is also sometimes used for short-wave transmission, frequently with the doublet in a horizontal position, which is totally contrary to all long-wave theory and practice.

LOADING THE ANTENNA

39. Distribution of Current and Voltage.—The antenna may be used at wavelengths longer than the fundamental by inserting a loading inductance at the base. The voltage and current distribution is changed by the loading, and is somewhat as shown in Fig. 18. Since the capacity of the loading coil *a* to ground is small, the current is practically uniform in the whole coil, but assumes a more or less sine-wave distribution in the antenna, as shown by curve *i*. On the other hand, owing to the inductive impedance of the coil *a*, there is a linear building up of voltage in the coil, so that the top of the coil is at high voltage with respect to earth. In the antenna itself, the voltage increases still further, following more or less the sine-wave law, as shown by curve *e*.

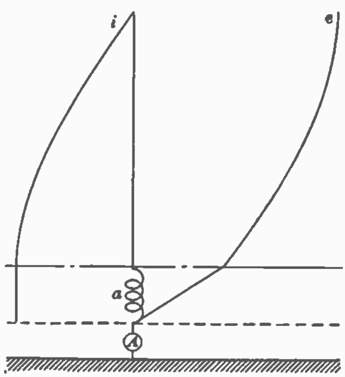


FIG. 18

The antenna can be operated at a wavelength lower than the quarter-wave fundamental by placing a condenser in series with the lead-in, in place of the loading inductance. Of course, it is necessary to keep some inductance at the base of the antenna for coupling to the transmitter, but this may be relatively small.

40. The antenna has distributed inductance and distributed capacity. If the antenna consists of more than one wire, the capacity is increased, but the inductance is decreased. If the wires are very close together, the decrease in inductance is proportional to the increase in capacity, as their product remains nearly constant, and the velocity of the current in the wires does not change much. This is the reason why the fundamental wavelength does not change much when more wires are added, provided the flat-top portion is narrow. If the wires are considerably separated, the capacity is increased in greater ratio than the decrease in inductance, which lowers the velocity and increases the fundamental wavelength.

41. Frequency of Closed Oscillating Circuit.—The frequency, or more specifically the *resonance frequency*, of an oscillating circuit is that electrical condition of the circuit when it is said to be tuned to the frequency in question. This condition obtains when the inductive reactance of the circuit is completely neutralized by the condensive reactance. By inductive reactance is meant the opposition, exclusive of plain resistance, of the circuit to high-frequency alternating currents caused by the presence of inductance. The inductive reactance is expressed by the formula

$$X_s = 2\pi f L \qquad (1)$$

in which X_s = inductive reactance, in ohms;
$\pi = 3.1416$;
f = frequency, in cycles per second;
L = inductance, in henrys.

The condensive reactance of a high-frequency alternating-current circuit is that opposition of the circuit, exclusive of resistance, caused by the presence of capacity. This may be expressed by the formula

$$X_c = \frac{1}{2\pi f C} \qquad (2)$$

in which X_c = condensive reactance, in ohms;
C = capacity, in farads.

42. The current in an alternating-current circuit does not follow Ohm's law. It is limited not only by the resistance of the circuit but also by the inductive or condensive reactance that may be present therein. The combined opposition of resistance and reactance is called *impedance*. When the value of impedance is known, the current may be calculated by the formula

$$I = \frac{E}{Z} \qquad (1)$$

in which I = current, in amperes;
E = electromotive force, in volts;
Z = impedance, in ohms.

The impedance is found by combining the resistance and the reactance as follows:

$$Z=\sqrt{R^2+(X_s-X_c)^2}\ ^* \qquad (2)$$

in which Z = impedance, in ohms;
R = resistance, in ohms;
X_s = inductive reactance, in ohms;
X_c = condensive reactance in ohms.

From the foregoing it is quite evident that when the inductive reactance is equal numerically to the condensive reactance, the subtraction of the one from the other in formula **2** will leave zero, so that the impedance will be equal to the ohmic resistance of the circuit. By reducing the ohmic resistance to a very low value it is possible to build up perceptible currents even with very minute voltages. This feature is exemplified in many of the coils and condensers used in radio-receiving sets.

43. It was shown that the only opposing action of an alternating-current circuit when the inductive reactance and condensive reactance are equal is the ohmic or simple resistance of the conductors. Expressed by a formula the condition of resonance obtains when

$$2\pi fL=\frac{1}{2\pi fC} \qquad (1)$$

In any closed oscillating circuit the resonance frequency, in cycles per second, may be calculated by changing the foregoing formula to read

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

*The simplest way to extract the square root of a quantity is by the use of logarithms. Detailed instructions are given in most textbooks on mathematics.

in which f = frequency, in cycles per second;
$\pi = 3.1416$;
L = inductance, in henrys;
C = Capacity in farads.

44. Frequency of Open Oscillating Circuit.—The antenna system may be considered an open oscillating circuit. In the case of a loaded antenna, the resonant frequency may be calculated approximately by assuming that the antenna capacity is concentrated, and using for the total inductance the inductance of the loading coil plus one-third of the distributed antenna inductance, thus

$$f = \frac{1}{2\pi\sqrt{\left(L + \frac{L_a}{3}\right)C_a}} \qquad (1)$$

in which L = inductance, in henrys of the loading coil;
L_a = distributed antenna inductance, in henrys;
C_a = antenna capacity, in farads.

Either the closed or the open oscillating-circuit formulas may be converted to terms of wavelength. The closed oscillating circuit formula becomes

$$\lambda = 1885\sqrt{LC} \qquad (2)$$

in which λ = wavelength, in meters;
L = inductance, in microhenrys;
C = Capacity, in microfarads.

Similarly, the open oscillating-circuit formula becomes

$$\lambda = 1885\sqrt{\left(L + \frac{L_a}{3}\right)C_a} \qquad (3)$$

in which λ = wavelength, in meters;
L = inductance of loading coil, in microhenrys;
L_a = inductance of antenna, in microhenrys;
C_a = capacity of antenna, in microfarads.

The antenna capacity C_a may be measured at low frequency. Ordinarily, it will vary from .0003 microfarad for a small receiving antenna, up to .01 microfarad for a large long-wave transmitting antenna.

EFFECTIVE HEIGHT OF ANTENNA

45. The effective height of an antenna may be defined as the height of an equivalent ideal antenna, having a uniform current in the vertical portion equal to the maximum current existing at any point in the actual antenna. In ordinary practice, this maximum current is usually at the base of the antenna, if the antenna is operated at a wavelength longer than the fundamental wavelength.

The effective height of an antenna would be the same as the total vertical height if the current in the vertical portion were uniform at a value equal to the current at the base, and there were no radiation from the horizontal portion. However, the current is never uniform in the vertical portion, so it is necessary to determine the distribution of the current and then calculate the average current, which will be less than the maximum current at the base of the antenna or other point of maximum current. For example, in Fig. 15, the average current would be the average of a sine wave with a maximum amplitude of I_b, where I_b is the current at the base of the antenna. Thus,

$$I \text{ average} = \left(\frac{2}{\pi}\right) I_b = .637\ I_b$$

46. The effectiveness of the antenna as a radiator on a given wavelength is determined by the product of the effective height and antenna current, or HI, which product is known as the *meter-amperes*.

Hence, for the simple vertical antenna, the value of meter-amperes is

$$HI = .637 \times I_b \times H$$

in which H = total height, in meters.

47. In actual installations it is customary to read the maximum current on an ammeter at the base of the antenna, and instead of using the product of the average current multiplied by the total height, it is much more convenient to refer to the maximum current I_b multiplied by the *effective height*. Obviously, the product of the maximum current and effective height should be numerically equal to the product of the average current and maximum height. This equivalence is illustrated graphically in Fig. 19, for the case of the simple vertical antenna. The actual current distribution is shown by curve *i*. The current at the base of the antenna is I_b. The meter-amperes may be considered as $h_1 \times I_1$ or $h_2 \times I_b$, where $h_2 = .637 h_1$, and $I_1 = .637\ I_b$. Then, $h_1 I_1 = h_2 I_b$, where h_2 is the effective height. In other words, the area *abdc* is equal to the area *efgc*.

48. If the antenna has a horizontal or flat-top portion, the current distribution is changed, as illustrated in Fig. 20. In effect, the current distribution is somewhat the same

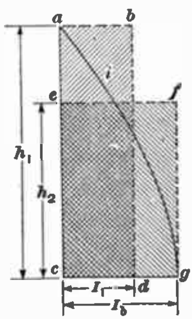


Fig. 19

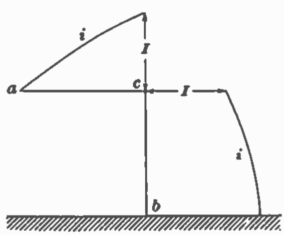


Fig. 20

as it would be if a vertical antenna of length *ab* were bent over at point *c*. It is modified somewhat by the increased capacity between the horizontal portion and the earth, which is greater than it would have been if the antenna had not been bent over at point *c*. The important feature to note in this figure is the fact that the average current in the vertical portion has been increased by adding the flat-top portion. In other words, the addition of the flat-top portion has increased the effective height.

The accurate calculation of the effective height of a complicated antenna structure is very difficult, as it is dependent on many factors, such as the presence of the towers, guy wires, and other conducting objects in the field of the antenna. It is also dependent to some extent on the amount of loading at the base of the antenna, the conductivity of the earth, whether or not a counterpoise is used, etc.

49. If the antenna has a large flat-top portion that is approximately horizontal, the effective height may be calculated from the height to the center of capacity of the actual antenna. To do this, the capacity C_1 of the flat-top portion to earth, is calculated by any reliable capacity formula. Then, after the antenna is installed, the actual antenna capacity is measured. The measured capacity is always greater than the calculated capacity, owing to the capacity added by the towers, down-leads, etc., which were disregarded in the calculation. If the measured capacity is called C_2, on the assumption that the center of capacity was lowered by the presence of the towers and down-lead, the final center of capacity of the actual antenna is located at a height h_2, thus:

$$\frac{h_2}{h_1}=\frac{C_1}{C_2} \qquad (1)$$

and

$$h_2=\frac{h_1 C_1}{C_2} \qquad (2)$$

Here, h_1 is the actual height of the flat-top portion, and h_2 is the height to the center of capacity, or the effective height.

In cases where the flat-top portion is considerably longer than the vertical length of the down-lead, calculation by the above method gives an effective height on the order of 70 per cent. of the actual height of the flat-top portion, and, in actual installations, the effective height determined by measurement of the field strength at a distance, has been found to agree very well with the effective height calculated by the center of capacity method.

ANTENNA RESISTANCE

50. If an antenna is replaced by an efficient air-dieletric condenser, having a capacity equal to the antenna capacity, and the circuit thus formed is tuned to resonance by the antenna loading coil, it will be found that the current in this circuit is much larger than the current that was obtained at the base of the antenna with the same power input, when the antenna itself was used in place of the condenser. Now, if a non-inductive resistance is added to the condenser circuit, the current can be brought down to the same value it had with the actual antenna for the same power input. If the condenser is an efficient air-dielectric condenser with negligible losses, the added resistance will consume energy at the same rate as the antenna, and the total effective resistance of the actual antenna is equivalent to the resistance added to the condenser circuit. The power consumed in either case is the same and is equal to I^2R, in which I is the current, and R is the resistance. Hence, we may define the antenna resistance as an effective resistance that is numerically equal to the quotient of the average power in the entire antenna circuit divided by the square of the effective current at the point of maximum current.

51. The total antenna resistance is composed of two portions; the radiation resistance, which represents power radiated, and the loss resistance, which represents power lost in the antenna.

The efficiency of the antenna is given by the following equation:

$$\text{Antenna efficiency} = \frac{\text{Power radiated}}{\text{Total power}} = \frac{I^2_b R_r}{I_b^2 R_t} = \frac{R_r}{R_t}$$

in which I_b = antenna current at the base of the antenna, in amperes;

R_r = radiation resistance, in ohms;

R_t = total antenna resistance, in ohms.

RADIATION RESISTANCE

52. The exact calculation of the radiation resistance is very complicated, as it is dependent on the calculation of the effective height, which is very difficult to calculate accurately for complicated antenna structures, as has already been mentioned. In addition to this, the radiation from the flat top should be taken into account.

For wavelengths above the fundamental, with antennas of known effective height, or simple antennas for which it is possible to calculate the effective height, the radiation resistance may be calculated approximately by the following simple formula

$$R_r = 160\pi^2 \left(\frac{H}{\lambda}\right)^2 = 1580 \left(\frac{H}{\lambda}\right)^2$$

in which R_r = radiation resistance, in ohms;
H = effective height of antenna, in meters;
λ = wavelength, in meters.

ANTENNA LOSSES

53. The losses in an antenna include ground resistance, radio-frequency resistance of conductors in the antenna circuit, equivalent resistance due to corona, eddy currents, insulator leakage, dielectric loss, etc. Ordinarily, the largest losses are the dielectric and ground losses.

The dielectric losses are due to the fact that the antenna is an imperfect condenser, and has objects in its field which have high dielectric absorption. If the antenna has a large flat-top portion, the electrostatic lines of force spread out for a considerable distance beyond the antenna, and if these lines of force encounter poor dielectrics, like trees, buildings, poorly conducting earth surface such as sand, etc., considerable energy is absorbed.

The dielectric losses can be greatly reduced by keeping the field of the antenna free from buildings, trees, bushes, etc., and by installing a net work of wires, called a *counterpoise*, underneath the antenna, to reduce the losses at the surface of the ground.

54. If the antenna is erected over sea water or highly conducting ground, the ground losses are usually small, but if the antenna is erected over dry sand, or other poorly conducting ground, the ground currents must travel a considerable distance through poorly conducting material to complete the circuit back to the transmitter. The ground can therefore introduce large conduction losses, as well as large dielectric losses, particularly at long wavelengths, where the dielectric losses are high. The use of a counterpoise, or ground network, greatly reduces the ground-conduction losses as well as the dielectric losses, as it provides a highly conducting path for the current to follow directly back to the transmitter. Instead of using a counterpoise suspended a few feet above the ground, a system of ground wires, similar to the counterpoise may be buried a few inches in the ground. The buried ground wires, in many cases, are practically as effective as the counterpoise system, although it is probably true that the dielectric losses would ordinarily be somewhat lower with the counterpoise than with the buried wires.

55. The losses in the antenna conductors are usually small compared with the dielectric and ground losses, but may be reduced by using larger conductors. However, the size of the conductors is usually determined by mechanical considerations, as a conductor that is strong enough mechanically, generally has sufficient conductivity to carry its share of the antenna current without much loss.

Other losses, such as eddy currents in the towers, corona or brush discharge, leakage over insulators, etc., are ordinarily small in a properly designed antenna.

DISTRIBUTION OF ANTENNA RESISTANCE

56. The distribution of the resistances in an antenna is shown in Fig. 21. Curve *a* shows the radiation resistance, which is an inverse function of the square of the wavelength. Curve *b* shows the dielectric, leakage, and corona loss resistance, which increases with increase in wavelength. Curve *c* shows the loss resistance due to eddy currents, and conduction loss in the antenna and ground conductors. This loss resistance decreases slightly with increase in wavelength, owing to decrease in skin effect, etc. Curve *d* is the sum of curves *b* and *c* and shows the total loss resistance. Curve *e* is the total resistance, including the useful radiation resistance, and is the

curve that would be determined by an experimental determination of the antenna resistance.

Owing to the fact that some of the losses increase with wavelength, whereas other losses decrease with wavelength, there is sometimes a point *f* on curve *d* where there is a broad minimum in the loss curve, and it is at, or near, this point that the antenna should be most efficient.

Sometimes, when the total resistance of the antenna is determined experimentally, the curve is not smooth, but

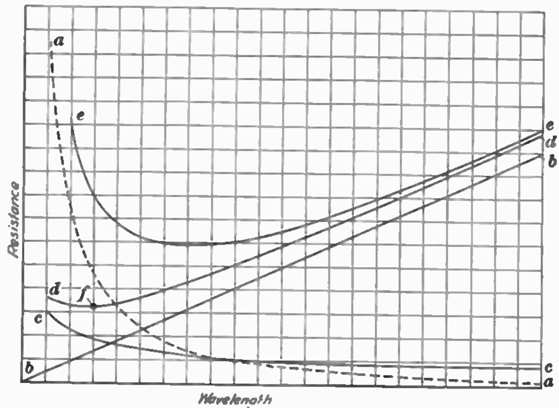


FIG. 21

has one or more decided peaks. These peaks are usually caused by something in the field of the antenna which absorbs energy at that particular wavelength, as, for example, resonance in a guy wire, a mast, nearby antenna, tin roof, or other mass of metal.

RADIO TRANSMISSION AS FUNCTION OF ANTENNA CONSTANTS

57. It has already been mentioned that, for a given wavelength, the effectiveness of a transmitter could be expressed in terms of *meter-amperes*, or the product of the effective height of the antenna by the antenna amperes. The effectiveness of a transmitter may be measured in terms of signal strength produced at a distance. It is customary to express this signal strength in terms of volts per meter of vertical height; that is, measured along the direction of an imaginary electrostatic line of force, as pictured in Fig. 2.

In actual practice, it is possible to make use of signals having a field strength as low as a few millionths of a volt per meter, so it is more convenient to express field strength in terms of microvolts per meter (1 volt = 1,000,000 microvolts).

58. The strength of the field radiated from an antenna can be calculated for any point on a theoretical basis, in so far as the effect of the spreading of the wave in all directions is concerned. However, it has been found that, in addition to the spreading effect, there is an absorption effect, caused by absorption of the wave as it travels along the surface of the earth. The absorption varies greatly with the character of the earth over which the wave passes. For sea water, the absorption is comparatively low, whereas, for dry sand, the absorption is very large. The absorption varies so greatly for different earth conditions that it is almost impossible to calculate the field strength for a signal received over land, without having considerable experimental data covering that particular route or a similar route.

For an oversea route, in daylight the strength of the signal is directly proportional to the antenna current and effective height at the transmitter, and is inversely proportional to the wavelength and the distance.

59. There is a decrease of the signal strength due to absorption, which differs for over-sea transmission in daylight and overland transmission. Overland transmission may cause the signal to drop down to only a small fraction of the value of oversea transmission. On the other hand, at night, on certain wavelengths, notably in the broadcast band, the waves appear to travel along the Heaviside layer, and do not suffer appreciable absorption. This is sufficient to account for the very long "freak" night range, so often noted on broadcast wavelengths, as, during the absence of heavy static, 50 to 100 microvolts per meter is sufficient to give fairly satisfactory broadcast reception, and a 5-kilowatt broadcasting station would produce a signal of that strength at a distance of 3,000 to 4,000 miles, if there were no absorption.

60. On the very short wavelengths, below 100 meters a complete change in transmission mechanism takes place, such that normal absorption does not take place, as on the longer waves. On wavelengths below 40 meters it has been found feasible to communicate over distances of thousands of miles, even in daylight. On these waves, however, there is a *skip effect*. At a short distance from the transmitter, the signal becomes very weak, or even may disappear entirely, but at some greater distance the signal can be heard again. As a rule, the shorter the wave, the greater the skip distance, and the greater the daylight range. Because of this skip effect, the very short waves are not adapted to short-distance communication, but may prove very useful for long-distance communication.

ANTENNA INSTALLATIONS

TRANSMITTING ANTENNAS

61. Design.—The higher the antenna is located above the earth connection, the greater will be its radiation and reception abilities. Transmitting antennas, in particular, must be installed with the view of obtaining considerable effective height with low losses. The design of receiving antennas is not so important, as the effect of the losses can readily be made up by increased selectivity and sensitivity in the receiver.

Except at very short wavelengths, it is customary to use a flat-top portion in the transmitting antenna. In the first place, because of the great cost of high towers, it is more economical to use lower towers, making up for the difference by lowering the losses and raising the effective height by using a flat top, thus making the most effective use of the towers. In the second place the increased capacity due to the flat-top section makes it possible to put more current into the antenna without exceeding the maximum safe voltage of the antenna insulation.

62. The flat-top portion is usually supported by two or more towers. For small antennas, these towers may be made of wood, but it is more common practice to use steel towers, as very strong supports are required to keep the antenna wires stretched up tight. If the wires are not kept taut, there will be considerable sag, which reduces the effective height and also causes the antenna constants to change in a high wind, as the antenna wires sway. The towers must be strong enough to stand the strain when the wires are loaded with sleet in high winds.

The antenna conductors must have considerable tensile strength, and yet must not be too heavy. Steel wire would be strong enough, but it has high losses due to skin effect. Copper-clad steel is frequently used with good results, particularly on long wavelengths, but stranded phosphor-bronze or silicon bronze are the most commonly used materials, as they have good high-frequency and conductivity with great tensile strength. Hard-drawn copper is often used for short spans.

63. Wires in Flat-Top Portion.—In order to increase the capacity of the flat-top portion, it is customary to use several wires. These wires may be supported by a horizontal cross-arm or bridge on top of the tower, or they may be supported by a wooden or metal spreader. The wires are usually separated 3 to 10 feet, as moderate separation is practically as effective as more wires with small separation and is much easier to maintain.

On shipboard, or in places where the flat top is difficult to maintain, *cage antennas* are often used. These consist usually of four wires equally spaced on metal rings 3 to 12 inches in diameter. These rings are placed at frequent intervals, so the antenna looks like a long squirrel cage or *sausage*. The lead-in system is sometimes a continuation of the horizontal cage construction. The cage antenna is very rugged and easy to maintain, but it has perhaps 20 per cent. to 30 per cent. less capacity than the same number of wires would have when spread out by a spreader.

If the antenna is operated at high voltage, say at 100,000 volts or more, corona or brush discharge is likely to appear at sharp points, particularly at the far end of the antenna. This is caused by the excessive voltage gradient near the surface of the wire, which breaks down the air, or ionizes it. The corona results in considerable loss, if the voltage is raised above the point where the corona starts. The break-down voltage will be raised if the area of the surface is increased, such as, by using a larger conductor, by attaching corona shields, or otherwise increasing the surface of the conductor at the break-down points.

64. **Counterpoise.**—It has already been pointed out that a counterpoise, or network of wires supported just above the ground and directly beneath the antenna, is very effective in reducing the dielectric and ground losses. On the longer wavelengths, this is very important, as the radiation resistance is often only a small fraction of an ohm with the highest towers it is economical to use, and in some cases, only 1 per cent. or 2 per cent. of the total antenna energy would be radiated, if the dielectric and ground losses were not reduced, as Fig. 21 shows. On short wavelengths, where the antenna is operated at the fundamental or below, the radiation resistance is so high that the dielectric and ground losses are small in comparison, and no counterpoise is necessary.

As the electrostatic lines of force spread out considerably beyond the antenna, it is a good rule to extend the counterpoise beyond the antenna, and off to the sides, for a distance comparable with the height of the antenna. The counterpoise should not be supported too high above the ground, as it takes the place of the ground and will tend to lower the effective height of the antenna if placed too high. Usually the counterpoise is supported 8 to 10 feet from the ground, just high enough to be out of reach. The counterpoise wires may be joined together at the transmitter end, and should be connected to the transmitter in place of the ground connection. The supporting structure of the counterpoise must be as rigid as that of the antenna.

In cases where it is not desirable to erect a counterpoise, a system of wires similar to the counterpoise may be buried a few inches in the earth. If the antenna is erected over highly conducting earth, like a salt marsh, it may be sufficient to bury a few copper plates near the transmitter for an earth connection, but, as a rule, the buried-wire ground system directly underneath the antenna is better.

65. Insulation.—Small antennas may be insulated with glass or high-grade composition insulators; but for very high voltages, long, glazed porcelain insulators are frequently used. In some cases the wires are individually insulated from the cross-arm or spreader, and in other cases the wires are attached directly to the spreader, and the spreader is insulated from the tower by a single large strain insulator.

66. Lead-In.—The lead-in should go as directly as possible from the transmitter to the antenna, and should not run too close to the tower or the walls of the building, because of eddy currents in metal objects and dielectric losses in other material, such as wood, brick, and concrete.

It has already been mentioned that the field of the antenna should be free from trees, buildings, and wire lines. Antennas erected on the tops of high buildings are sometimes ineffective at certain wavelengths, presumably because of counter-radiation from the building itself, and absorbing and reflection effects in nearby buildings.

In case the towers are guyed, the guy wires should be broken up with insulators at frequent intervals to prevent loss of energy due to circulating currents through the guys and the mast.

RECEIVING ANTENNAS

67. General Instructions.—The remarks made about transmitting antennas used to apply with equal force to receiving antennas back in the days of the crystal or other non-amplifying detectors. With the advent of the vacuum tube and radio-frequency amplification, it is possible to obtain very good results with receiving antennas that would be very inefficient as transmitting antennas. It is true that, with many types of receivers, the antenna would tune sharper and would give more signal strength if used with a counterpoise, and all precautions were taken to reduce losses, but it is seldom done, as most receivers will go down to the static level with a very inefficient antenna. However, some of the points mentioned for transmitting antennas are well worth keeping in mind for receiving antennas, such as, keeping the lead-in away from the building as much a possible, making the antenna as high as possible above the receiver, running the ground lead direct to a good ground, erecting the antenna over a clear space free from buildings, wires, and trees, insulating the antenna well to prevent leakage, etc.

68. **Antenna Conductors.**—A single wire is practically as good as several spaced wires as far as reception is concerned, as the loss in effective height would be so small as to be hardly noticeable on the receiver. The total length of antenna to use depends on the wave length, and, to some extent, on the type of receiver, but, as a rule, the longer the wire, the stronger the received signal will be. On the other hand, as the length of the wire is increased, the selectivity decreases and directive effects may become noticeable. In any case, the fundamental wavelength of the antenna should be lower than the shortest wavelength that it is desired to receive, except, possibly, for waves below 100 meters. For example, consider an antenna for broadcast reception. The shortest wavelength to be received is about 200 meters, say. The fundamental wave-length should be below 200 meters, so the greatest length of wire that should be used is $200 \div 4.2 = 47.6$ meters, or 156 feet; so any length from 30 feet to 150 feet might be used, depending on whether selectivity or increased signal strength is desired. The average of the two extremes, or 90 feet, would be a good compromise. It should be remembered that this length includes the length of the horizontal part as well as the length of the lead-in.

69. **Ground Connection.**—A water pipe is usually a good ground connection for receiving. The ground lead from the

receiver should be as short as possible and should be securely connected to the pipe by soldering or by using a good ground clamp, similar to that shown in Fig. 22, the pipe being thoroughly cleaned before the clamp is attached. If the water-pipe system is extensive enough, it might serve as a counterpoise in cases where it makes poor contact with the earth, but, as a rule, it is desirable to have the pipe make good contact with the earth.

70. Lightning Arrester.—It is essential to protect the receiving set from possible damage by lightning, either by putting in a heavy single-pole double-throw switch, or by using an approved vacuum or other type of lightning arrester, or both, according to the local fire underwriters' rules. The connections to a lightning arrester are shown in Fig. 23, where the arrester is shown at *a*. One terminal of the arrester is connected to the lead-in *b*, and the other to the ground *c*. The lead-in *b* enters the building through a porcelain pipe *d*.

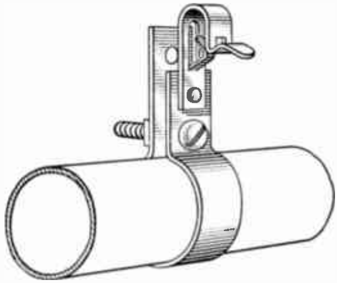


FIG. 22

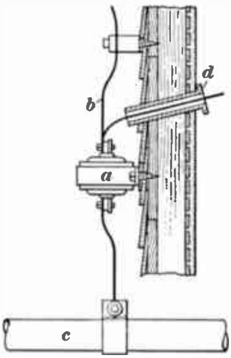


FIG. 23

If it is necessary to use both a lightning arrester and a switch, the lightning arrester will protect the receiver while it is in use. When the receiver is not in use, the antenna switch should be thrown down to disconnect the antenna from the receiver, and connect it directly to ground. This may be accomplished by connecting the antenna to the blade of the switch, the receiver to the top contact, and the ground to the bottom contact. The ground switch should preferably be placed outside of the window, with the ground wire running as directly as possible to a ground rod, buried plate, or outside water pipe. The ground wire should have somewhat greater current-carrying capacity than the antenna lead-in, but, in any case, it should not be smaller than No. 14 B. & S. gauge copper wire. This is to make sure that the antenna lead will burn off before the ground lead burns off, in case of a direct stroke of lightning or accidental contact with power wires.

If necessary to cross other wires with the antenna, the crossing should be made as near to right angles as possible to minimize inductive interference. It is not advisable to erect an antenna across a high-voltage power line or trolley line, as it would obviously be very dangerous if the antenna should break and come in contact with the high-voltage wires.

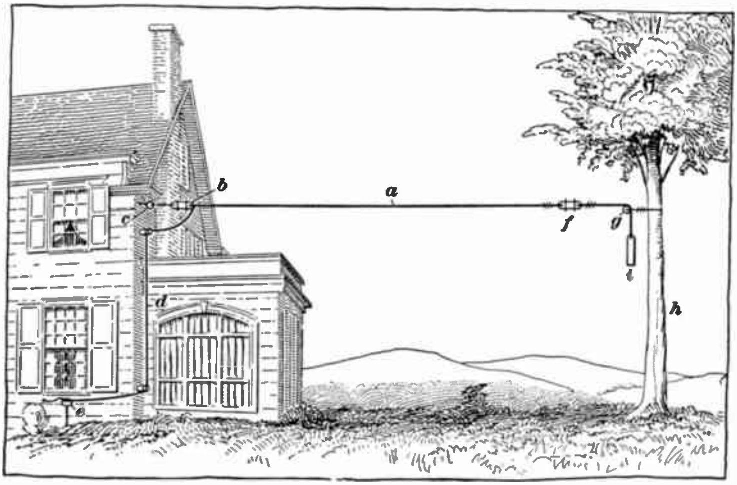


FIG. 24

71. Light-Socket Antenna.—Sometimes the house-lighting circuit can be used as a receiving antenna with good results, particularly if the feeders from the outside transformer come in for some distance on the poles. Generally, one side of the lighting circuit is grounded, so better results may be had with one side of the lighting circuit than the other. A small, well-insulated condenser should always be placed between the lighting circuit and the receiver, as, otherwise, the lighting circuit may be short-circuited through the receiver. Such coupling condensers are available in commercial form already combined with an electric-light plug and provided with suitable terminals.

72. Typical Installations.—A typical outdoor antenna installation is shown in Fig. 24. One end of the antenna conductor *a* is fastened to the strain insulator *b* which in turn is fastened by means of a short piece of wire to the screw eye *c*

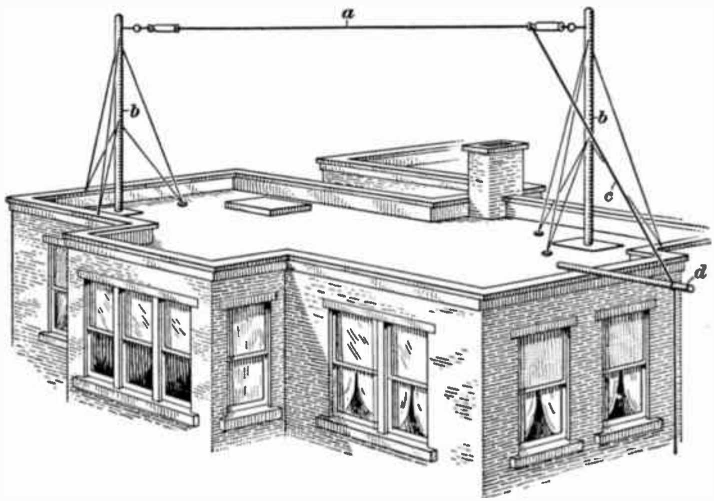


FIG. 25

in the side of the building. The lead-in *d* is electrically connected to the antenna conductor *a* and is brought to the side of the building and fastened rigidly in position by means of porcelain knobs. The free end of the lead-in is fastened to one terminal of the lightning arrester *e*, and from there it goes through a porcelain tube to the inside of the building. The other terminal of the arrester *e* is connected to ground, as shown in Fig. 23.

The far end of the antenna conductor *a*, Fig. 24, is connected to another strain insulator *f*. A pulley *g* is fastened to a tree *h*, or some other rigid support like a pole, tower, or an adjacent building. One end of a fairly strong cord is fastened to the free end of the strain insulator *f*. The other end of the cord is threaded over the pulley wheel *g*. A weight *i*, which may be a window sash weight is fastened to the cord to hold the antenna wire taut. Instead of the pulley and weight, one may use a large spiral spring to accomplish the same purpose.

73. Where the space surrounding a building is limited, for example near apartment houses, it is not practical to install an antenna like that shown in Fig. 24. One way of overcoming this difficulty is to install the antenna on the roof as shown in Fig. 25. The antenna wire *a* is supported on two masts *b* with the usual insulators in the antenna circuit to prevent direct connection to the masts. The lead-in *c* is fastened to the end of a prop *d* and allowed to go downward to the point where it is to enter the building. A similar structure may be erected on two adjacent tall buildings.

74. Where it is not practical or permissible to install an outdoor antenna, one may string enough wire inside the building to pick up some of the radio energy. The wire may be suspended on insulators in the attic. Insulated wire may be placed around the picture molding. A copper or bronze screen 3 feet wide and about 10 feet long suspended in the attic will also serve the purpose. In all cases a lead-in wire must extend from the antenna to the set. If no part of the antenna system extends outside the building, no lightning protection is required.

RADIO TUBES

Serial 2475 Edition 1

RADIO-TUBE THEORY

FILAMENT EMISSION

BRIEF REVIEW OF ELECTRON THEORY

1. Electron Movement.—The study of radio tubes, or vacuum tubes as they are frequently called, involves a consideration of the fundamental principles of electron movements. *Electrons* are the smallest particles into which electricity may be divided, and represent minute electric charges, which are negative in character. The particles of matter called *protons* carry charges of positive electricity, and each of these has a mass relatively larger than that of an individual electron. Any material normally has enough electrons accompanying the body, with a certain number of protons and electrons as its *nucleus*, to exhibit no electrical effect since, in a stable state, there is an equal balance of negative and positive electric charges. An uncharged body may lose an electron, in which case it will exert a force tending to attract and attach a negative, or unlike, charge in the form of another electron.

The electrons are in constant rapid motion within the atom, and the number of electrons depends directly on the chemical nature of the material. The motion becomes more rapid as the temperature rises, and diminishes as the temperature is reduced below any given point. Molecular motion is thought to stop at a temperature of absolute zero. Some certain materials give off electrons more freely at any one temperature than do other substances which retain their electrons very tenaciously even at quite high temperatures.

2. The filament, or cathode, in a radio tube makes direct use of the liberation of electrons by a heated substance. This usually takes the form of a heated wire, although some other emitting surface may be used. The filament, when heated or lighted in a vacuum, is surrounded by a cloud-like formation of electrons in rapid motion, much like the miniature cloud of vapor that hovers over a pan of boiling water. These electrons have no place in particular to go, and a large portion of them remain close to the filament. A few wanderers pass beyond the neighborhood of the filament, whereas many will eventually return to it. These free electrons combine to produce an effect that tends to prevent the release of electrons from the filament. The influence exerted by this field of electrons is called a *space-charge effect*.

3. Edison Effect.—The introduction of a collector agent, or a plate, near the filament in a vacuum will show evidence of the presence of electrons. Some of the wandering electrons will strike the plate and give it a negative charge. If the plate is connected to the positive end of the filament, the so-called Edison effect will be produced, and a measurable current will be observed in the connecting conductor. The plate, being connected to the positive filament terminal, will possess a small positive potential with respect to the remainder of the filament, which potential will cause the plate to collect a large number of the negatively charged electrons. In their progressive travel these electrons will combine their minute charges of electricity, which will result in an electric current. The connection of the plate to the negative filament terminal will give the plate a small negative potential with respect to the filament and hence cause the plate to repel or prevent the collection of any negative electrons.

4. Direction of Electron and Current Flow.—A battery connected in the plate-return lead in such a manner as to give the plate a positive charge will cause the plate to collect more electrons than would otherwise be the case, and to produce a considerable electric current. The connection of the battery in the reverse direction so as to make the plate negative, would effectually prevent the collection of electrons and the production of an electric current. The direction of travel of the electrons with the plate positive is from the filament to the plate or from negative to positive. Before this phenomenon was known, the direction of an electric current was defined as a flow of electricity from a point of positive potential to one of a relatively negative potential. It is important to keep this point in mind in the study of the operation of radio tubes.

5. Application of Electron Theory to Radio Tubes.—The fundamental circuits of a radio tube are shown in Fig. 1. In this diagram the filament of the tube is shown at *a*, and the plate is at *b*. The filament is heated by current supplied by the filament battery, commonly known as the *A* battery. In series with this battery and the filament of the tube is a rheostat, or variable resistor, *c*, by means of which the filament current, and consequently the filament temperature, may be regulated.

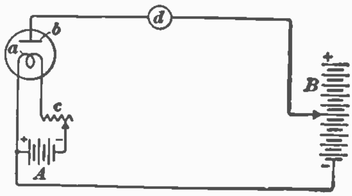


Fig. 1

The plate *b* of the tube is connected to the positive terminal of the plate battery, generally called the *B* battery, and so lettered in the diagram. A milliammeter *d* is connected in the *B*-battery lead, to show the amount of current in the plate circuit. The negative terminal of the *B* battery is connected to one of the filament leads.

The stream of negative electrons from the heated filament *a* to the positive plate *b* establishes an electron current, which is also an electric current and is indicated on the milliammeter *d*. However, the electron current, as produced by the electron stream, is from the filament to the plate, whereas the electric current is considered to be from the point of positive potential to the point with a more negative voltage. Since the electron current is in the plate circuit it is commonly called a *plate current*, in distinction from the current in the filament circuit, which is called the *filament current*.

SPACE-CHARGE AND SATURATION EFFECTS

6. The number of electrons attracted to the positive plate *b*, Fig. 1, and the resultant current depends on the amount of potential applied to the plate, other factors as filament temperature remaining fixed. As the plate potential is raised sufficiently, most of the available electrons will be drawn to the plate, and a further increase in plate potential will not increase the plate current appreciably. This is termed the *saturation current*, and since it is an indication of the total number of electrons emitted, this current may also be called the *emission current* or *filament emission*.

The number of electrons released by the filament is practically constant for a given filament temperature. These electrons hover near the filament, and, as has been explained, form a sort of cloud around it. This gives the space surrounding the filament a negative charge, because of the individual negative charges of the emitted electrons. This charge is commonly known as a *space charge* and represents an accumulation of electrons that may be utilized to establish a plate current. Normally, only a portion of the space charge is used to establish a plate current. When the plate potential is made high enough to attract all the electrons just as rapidly as they are released by the filament, the space-charge effect is reduced, and the condition of saturation is obtained.

If the filament temperature is raised, more electrons are emitted. The plate potential may then be raised to produce a still greater plate current, before another saturation point is reached. Still higher filament temperatures will result in still greater plate-current values before further saturation points are reached. In general, the higher the filament temperature, the higher the emission-current values before the saturation effects become effective.

RADIO-TUBE FILAMENTS

7. Tungsten Filament.—The earliest filaments for radio tubes were made of tungsten, as this material had been in extensive use for lamp filaments, and its characteristics were well known. Even now tungsten filaments are commonly found in the larger transmitting tubes. This is largely due to the ability of tungsten filaments to withstand the high-velocity bombardment accompanying relatively high plate-voltage operating conditions which would ruin the active surfaces of the other types of filaments. It is necessary to operate such a filament at a rather high temperature in order to secure good emission economically. Operating the filament at voltages above the rated normal value will reduce the life of the tube because of the rapid evaporation of the tungsten wire. Conversely, reduced operating temperatures will result in longer life.

8. Oxide-Coated Filament.—The study of filament requirements has resulted in the development of a method for coating the surface of the wire with materials capable of producing a relatively large number of electrons at a moderate operating temperature. This permits of operating the filament at a temperature low enough to give a very long life. The coating is such as to produce, or liberate, a large number of free electrons at a relatively moderate filament temperature corresponding roughly with a dull reddish color. Barium and strontium oxides have been widely used and possess general characteristics adapting them to service as coating materials. The filament may be of platinum ribbon or some other suitable metal or alloy. In order to make the electron emitting surface area as great as possible for a given cross-sectional area of filament, the wire is ordinarily made in the shape of a thin ribbon. Extreme care must be exercised in applying the coating, which is ordinarily accomplished by successive dipping or continuous bath applications until the desired amount of coating material has been deposited. In addition to supporting the oxide coating, the filament wire also acts as a heater element to bring and keep the oxides at their proper operating temperature. It is possible to coat other surfaces than filaments, such as cylinders, which may be heated indirectly from enclosed filaments.

9. Thoriated Filament.—Certain metals such as thorium, produce an abundance of electrons and, incidentally, melt at temperatures considerably below that required by tungsten. Pure thorium filaments are difficult to make. However, a moderate amount of thorium may be combined with tungsten, so that the tungsten acts as a heater and supporting medium. The thorium, in a small amount, is introduced into the filament wire in the early stages of manufacture and is distributed throughout the body of the filament. After the tube is exhausted, the surface of the filament must be placed in an active condition by treatment which will produce a surface layer of thorium. This filament will possess most of the high emission characteristics of thorium itself.

The filament must be operated at such a temperature that enough thorium will diffuse to the surface to maintain an active layer. The useful life of the filament will be completed when the available thorium is all used up. In case the tube has been improperly operated or overloaded, the thorium layer may often be restored by a process known as reactivation.

10. Special Filaments.—In some cases where unusual operating characteristics are desired, it may be necessary to employ filaments made of special materials. These may further be included in a gas atmosphere of any special type, in order to produce other features of operation impossible to secure by any other method. In general, these requirements are special and of rather limited application. Such treatment of the subject as may be necessary will be found in the discussion of the tubes having the special characteristics.

11. Effect of Gas.—The presence of even a few atoms of gas in a radio tube is very objectionable, except for those types which depend for operation on special gases. An atom of gas in the electron stream, or plate-current path, will sooner or later be struck by a rapidly moving electron, whose velocity will cause it to collide with the atom with sufficient force to liberate some of the attached electrons, leaving the atom with a positive charge. The freed electrons will be immediately attracted by the plate and move thereto, thereby augmenting the normal plate current. The positively charged atom or ion, on the other hand, will travel toward the filament, which is at a relatively negative potential, hence exerts a strong attracting force. The collision of the large ion with the filament is disastrous to the surface, as it produces a miniature pit in that surface. An additional effect that is equally serious with the coated and thoriated types of filaments is that the collision will damage the surface-emitting properties of the filament at that point. Continued bombardment of the filament by the positive ions will in time seriously reduce its structure or activity, if not damage it permanently.

If there is enough gas present inside the tube it will frequently produce a characteristic blue glow when the tube is operating. This glow should not be confused with the fluorescence effect sometimes observable in the vicinity of oxide-coated filaments when operating, or with gases which may be used in the tube to secure special requirements of operation. The presence of gas in a tube frequently indicates that it has been subjected to overload conditions. If the amount of gas is not large it may frequently be removed by operating the tube under light load conditions for a period of one hour or more.

12. Extreme care is exercised in the process of manufacture to remove the free gas from the tube, and as much gas as possible from the internal parts. The metal parts are carefully heated, as is also the glass bulb, to liberate the occluded gases from the metal and glass so this will not occur after the tube is placed in service. A material which volatilizes readily and which has a strong affinity for gas is volatilized in the tube to help in the final clean up of gas during manufacture. Magnesium, aluminum, calcium, and other materials are widely used in this connection. This material is called the *getter* and forms a coating, sometimes silvery in appearance, as it settles on the interior of the bulb. During the final stages of manufacture coils carrying radio-frequency currents are closely coupled with the metal parts in the tube to heat them by induction, and in turn flash the getter to combine with the final traces of gas, and deposit them on the interior wall of the tube or bulb.

THERMIONIC TWO-ELEMENT TUBE

TYPES OF TWO-ELEMENT TUBES

13. Two-element tubes have, as the name implies, two active elements, or electrodes, both necessary for the conduction of electricity through the tube. The electrode from which electricity flows through the tube is called the *anode*, while that electrode to which the electricity flows is the *cathode*. All two-element tubes, when operating as they should, will conduct current in only one direction; namely, from the anode to the cathode.

There are two general types of two-element tubes; namely, those in which the operation is based on one heated element and one cold element, and those in which both elements are initially cold. Those with one heated element are called thermionic vacuum tubes; the others may be called non-thermionic, or gaseous, tubes.

THEORY OF TWO-ELEMENT THERMIONIC TUBE

14. The thermionic two-element tube is dependent in its operation on one heated element that gives off electrons and one element with a positive charge to attract these emitted electrons. The two elements are placed in a bulb from which most of the air has been taken and the connections to the elements are made by means of conductors carried through the stem of the bulb.

The simple circuit diagram shown in Fig. 1 may be used to study the characteristics, or peculiarities, of the two-element tube. The filament circuit is first adjusted to a low voltage, say 5 volts, and then the plate current is measured at different plate voltages. The voltage and current values may then be plotted as indicated in Fig. 2 where E_f indicates filament voltage. This figure does not show the exact characteristics of any commercial tube, but merely indicates, in a general way, the values of plate current for different filament and plate voltages.

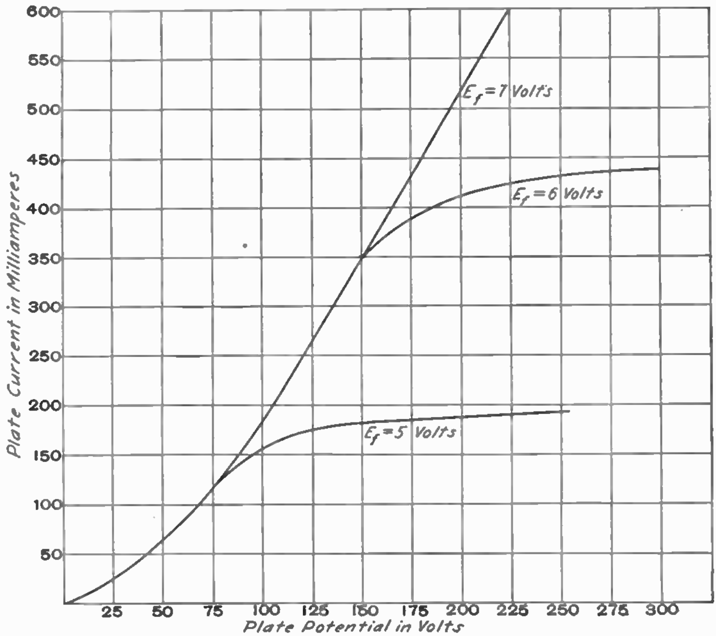


FIG. 2

15. With 25 volts applied to the plate, the plate current, Fig. 2, is about 25 milliamperes. As the plate voltage increases, the plate current also increases rapidly up to about 80 volts plate potential. With 5 volts on the filament, the plate current does not increase so rapidly as the plate potential is increased from 80 up to 100 volts. At 100 volts plate potential the space-charge effect is almost exactly neutralized, as all the electrons emitted by the filament are being drawn to the plate. This may be considered as the saturation point for the given filament voltage.

When the filament voltage is raised to 6 volts, the plate current increases with the plate voltage up to 150 volts. Further increase in plate voltage does not increase the plate current as much as before, and another saturation point is soon reached. With 7 volts applied to the filament, the plate current reaches a much higher value before it finally reaches a saturation point.

TWO-ELEMENT TUBE USED AS RECTIFIER

16. Half-Wave Rectifier.—The two-element tube is best adapted for rectifier service. This is because of the fact that it will allow current to pass in only one direction; namely, when the plate is positive with reference to the filament. For rectifier service, the two-element tube may be connected as shown in Fig. 3. The primary winding *a* of the transformer connects with an alternating-current supply line. The secondary winding *b*, known as the filament winding, gives a low-voltage output for heating the filament of the rectifier tube.

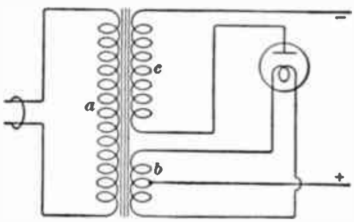


FIG. 3

Another secondary winding *c*, known as the plate or high-voltage winding, supplies an alternating potential to the plate of the tube. Current passes in the plate circuit only when the plate is positive, so that the output is a direct pulsating current, having the polarity indicated by the + and − signs in the figure.

17. Full-Wave Rectifier.—Two two-element tubes may be so connected in a circuit as to utilize both sides of the alternating-current supply. Such an arrangement is shown elsewhere. The output current capacity from the rectifier is thus virtually doubled with the same tube operating conditions and the shape of the output current wave is greatly improved.

A single tube of special construction may be used for full-wave rectification. Such a tube consists of two plates with a separate filament section for each plate.

THREE-ELEMENT TUBE

GRID ELEMENT

18. The three-electrode tube has, in addition to the filament and plate electrodes, an intermediate, or control, electrode called a *grid*. The grid, by the application of suitable potentials, acts to neutralize the space-charge effect or to strengthen its influence, and thereby controls the electron stream or plate current. The grid is usually of a grid-like, or

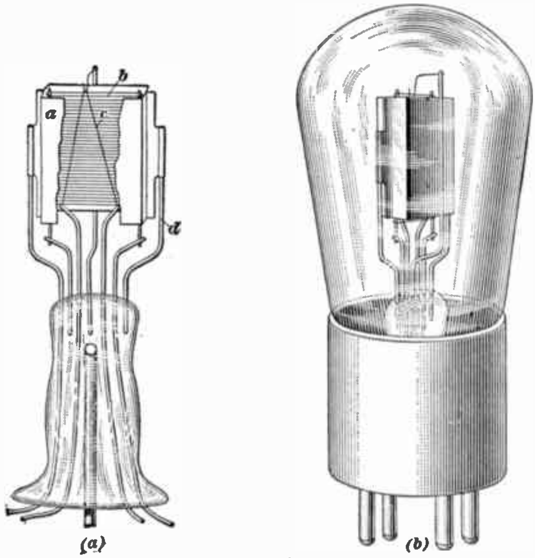


Fig. 4

skeleton, construction, hence the name. It is placed between the filament and plate and is therefore directly in the electron path.

The grid may be conveniently made from round wire wound on a form of the desired shape with the wires welded or otherwise attached to suitable support wires to hold the turns permanently in position. The form may be made so as to give the final grid its proper shape and size, after which the form is removed. Where special operating or extra-strength features are needed, longitudinal wires are also added. Sometimes special wire or special treatment of the grid is necessary in order to secure the required characteristics. Such is the case with some of the power or transmitting tubes where the operating temperature of the grid assembly may be quite high.

19. In appearance the three-element tube resembles the two-element tube. Usually, only the plate and filament are visible, and the latter only when it is heated. In order to obtain an idea of tube construction, reference may be made to Fig. 4, where in view (*a*) is shown the stem with all the elements mounted in position and in view (*b*) is shown the entire tube. The plate *a*, view (*a*), is shown partly broken so as to permit one to see the other two elements. The grid *b* is in the form of a flattened helix, which is rigidly supported at each edge. The grid then forms a cage-like structure all around the filament *c*, except that the ends are open. The grid can thereby affect the passage of electrons from the filament to the plate. The filament *c* is rigidly supported by posts of heavy wire. The top support is insulated, the terminals of the filament being connected to the bottom supports. The grid and plate each have two supports which are rigidly fixed in the glass stem. One of the supports of each element, like that shown at *d*, ends in the stem. The other support extends to the bottom of the stem and forms a connection for its element. The four conductors at the bottom of the glass stem establish connections to the plate, grid, and filament elements. In the completed tube, as shown in view (*b*), the connection to the elements is made by means of the pins or prongs shown in the base of the tube.

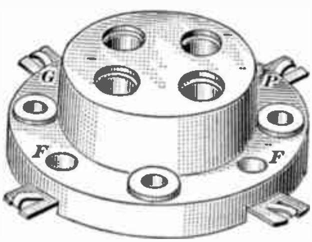


Fig. 5

20. A necessary accessory with every tube is a tube socket, one type of which is shown in Fig. 5. The socket is usually a permanent fixture in the device in which the tube is used, as, for example, in a radio-receiving set. When the tube is inserted into the socket, the connections to the elements are extended to the socket terminals, as shown at *P*, *G*, and *F*, where *P* is the plate terminal, *G* is the grid terminal, and *F* identifies the two filament terminals. The filament pins in the base of a radio tube are usually of a larger diameter than the grid and plate pins, hence the holes in the tube socket, which correspond to the diameter of the pins, will receive the tube in only one way. From the terminals of the tube socket the connections are extended to other parts in the unit in which the tube is used.

ACTION OF GRID

21. The action of the grid in the three-electrode tube is basically like that of a controlled space-charge effect. The operation of such a tube is like that of the two-electrode type with the addition of the control electrode. Thus, the filament produces a large quantity of electrons and the resultant space-charge effect is produced. The plate is maintained in service at a high positive potential, and tends to collect a number of electrons dependent on the relative values of the space-charge and plate-control, or attraction, effects. The grid being close to the space-charge field, can exert a predominating influence on the electron, or plate-current, flow. The space-charge effect, which is negative, may be increased or decreased at will by the application of suitable potentials to the grid. Thus, a negative potential applied to the grid will assist the space-charge effect in preventing the flow of electrons from the filament to the plate, and may even be made great enough to stop their passage completely. If a positive potential is applied to the grid, the space-charge effect will be diminished to some extent and more electrons will pass to the plate than without the positive potential on the grid. While this positive potential is applied to the grid, the grid will attract some electrons and a grid current is set up which is made use of in some types of service.

CHARACTERISTIC CURVES

22. Tube Circuit.—A three-element tube circuit arranged for measuring the plate current with various grid voltages is shown in Fig. 6. The tube is shown here in schematic form, just as one sees it in technical publications, with the filament at *a*, the plate at *b*, and the grid at *c*, The filament is heated by current from the *A* battery. A rheostat *d* in the filament circuit enables one to apply the correct voltage to the filament terminals of the tube. The *B* battery supplies the plate potential. It will be noted that the positive (+) terminal of the *B* battery is connected to the plate *b* of the tube, and the negative (−) terminal of the *B* battery to the negative filament terminal. This makes the plate positive with reference to the filament and obtains the required condition of establishing a flow of current in the plate circuit, which is indicated on the milliammeter *e*.

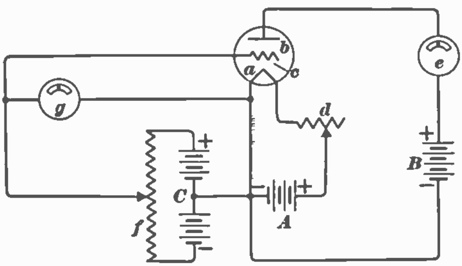


FIG. 6

23. The grid circuit, Fig. 6, extends from the grid *c* of the tube through the connecting wiring and *C* battery to the negative terminal of the tube. A potentiometer, or voltage divider, *f* across the *C* battery enables one to apply various positive and negative voltages to the grid. The terms positive and negative relate to the electrical condition of the grid with reference to the negative end of the tube filament. A voltmeter *g* connected across the grid and negative filament indicates the values of voltage applied to the grid.

24. Grid-Voltage Plate-Current Curves.—In order to show the manner in which the plate current changes with variations of voltage in the grid circuit, measurements will be made on the general-purpose tube, known as type 201-A. This tube requires 5 volts at the filament terminals, and for

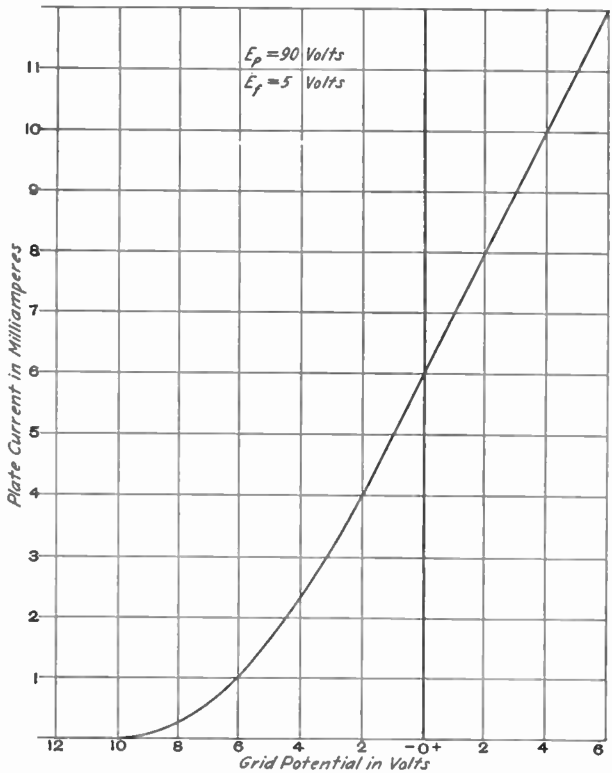


FIG. 7

these measurements 90 volts is applied to the plate circuit. The designation for plate voltage is E_p, for filament voltage E_f, and for grid voltage E_g. Similarly, plate current is usually written as I_p, grid current as I_g, and filament current as I_f.

As has already been mentioned, the plate voltage is maintained at 90 volts and the filament voltage at 5 volts. The change in plate current will now be entirely produced by varying the grid voltage. When the slider of the potentiometer *f*, Fig. 6, is brought to a point where the voltmeter shows zero grid voltage, the milliammeter *e* indicates a current of 6 milliamperes. This value is indicated by a dot on the squared paper drawn as shown in Fig. 7. The position of the dot is found by following the zero grid-voltage line upwards until it comes to the horizontal line corresponding to the value of the current indicated on the milliammeter. In this case the dot is placed at the point where the zero grid-voltage line intersects the 6-milliampere line.

When this is done, the slider of the potentiometer *f*, Fig. 6, is moved toward the negative end of the *C* battery until a reading of −2 volts is obtained on the voltmeter. The plate milliammeter indicates a current of 4 milliamperes. Again this value is marked on the diagram, Fig. 7, on the vertical line corresponding to −2 volts grid potential at the point where this line cuts the 4-milliampere line. It should be noted that the values of grid voltage on the left of the zero line are negative and those on the right are positive. The grid voltage is further varied and the corresponding values of plate current are noted. The values will be found to be as follows:

Grid Voltage	Plate Current	Grid Voltage	Plate Current
0	6	− 8	.4
−2	4	−10	0
−4	2.4	+2	8
−6	1.1	+4	10

25. When these values are accurately placed on the diagram, Fig. 7, a line may be drawn as shown, which is known as a grid-voltage plate-current curve. It will be noted that this line is nearly straight from about 4 milliamperes, corresponding to −2 volts grid potential, to 10 milliamperes, corresponding to +4 volts grid potential. Within this range 1 volt change of grid potential produces an equal change of plate current. Below 4 milliamperes, the change in plate current is much smaller for the same change in grid voltage. The gradual bend in the lower end of the characteristic curve is of importance for certain purposes and it is well to observe how this bend was obtained.

A curve like that shown in Fig. 7 is of great value to the radio engineer. It enables him to determine at a glance the characteristics of a radio tube. The plate-current curve for most tubes resembles that shown in the figure, although the numerical values of grid voltage and plate current will vary with different types of tubes and different plate potentials.

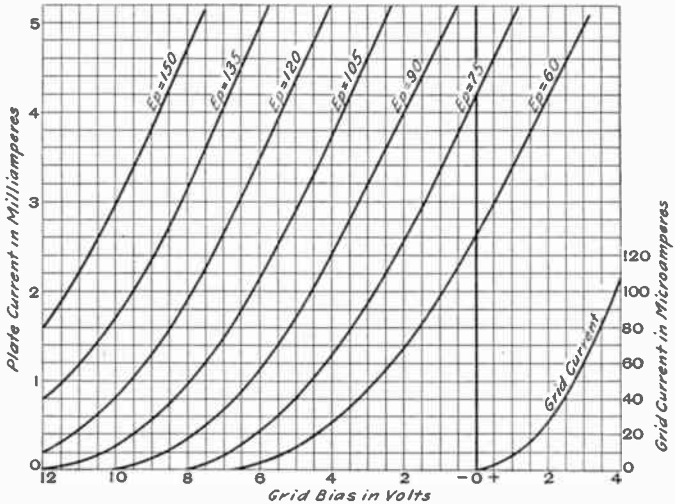


FIG. 8

26. A number of curves may be combined in one figure to show the characteristics of a tube under different operating conditions. The curves in Fig. 8 show the grid-voltage plate-current condition of the 201-A type radio tube with plate potentials E_p of 60 to 150 volts. The grid-current curve shown in the lower right-hand corner is useful in some types of service. This curve is obtained with positive grid potentials, and is usually steeper with the lower plate potentials.

A few comparisons selected at random from the different curves may help to show the usefulness of the curves. With a grid bias, or grid potential, of −6 volts, the plate current is about .1 milliampere at 60 volts plate potential; .4 milliampere at 75 volts; 1.1 milliamperes at 90 volts; 2.1 milliamperes at 105 volts; 3.5 milliamperes at 120 volts; and 5 milliamperes at 135 volts. The highest plate-current curve goes beyond the range of this chart, but the magnitude of the current with 150 volts plate potential and −6 volts grid bias is about 6.5 milliamperes.

27. Another item worthy of note is the change of plate current for a given grid-voltage change at a certain specified plate potential. On the 90-volt curve, Fig. 8, for example, an increase from −2 volts grid bias to −3 volts reduces the plate current from 4 to 3.2 milliamperes, a change of .8 milliampere. Similarly, decreasing the grid bias from −2 to −1 volt, increases the plate current from 4 to 4.8 milliamperes, another change of .8 milliampere. A change of 1 volt on the −6 volt grid-bias line on the same curve shows an increase of .6 milliampere, and a decrease of .4 milliampere. In the first case the change in plate current for 1 volt variation in grid voltage was .8 milliampere. In the second case, the change in plate current was greater when the negative grid voltage was reduced by 1 volt than when it was increased by 1 volt. In other words, the change in plate current near the lower bend of the characteristic curve is not the same for equal grid-voltage changes, whereas on the straight portion of the curve, a unit change in grid voltage produces an equal change in plate current.

AMPLIFICATION FACTOR

28. Amplifying Action of Three-Element Tube.—The three-element tube is inherently an amplifier of voltage, current, or power. A change in grid voltage produces the same effect on the plate current as a much larger change in plate voltage. The power (IE or I^2R) used up in the grid circuit is very small, since the grid does not ordinarily carry any current, yet the small input power in the form of voltage on the grid is capable of controlling a much larger amount of power in the plate, or output, circuit.

The change in plate current for a given grid-voltage change as compared with a plate-voltage change giving the same change in plate current as the small grid-voltage change, represents the amplifying action of a tube. This feature is usually expressed as a ratio between the change in plate voltage and the change in grid voltage, and is termed the *amplification factor*, or μ (Greek letter, pronounced mū) of a tube.

29. Determining Amplification Factor from Curves.—When a set of curves, like those shown in Fig. 8, is available, the amplification factor can be easily determined. With -6.5 volts on the grid and 120 volts on the plate, the plate current is 3 milliamperes. The same value of plate current is obtained with -10 volts on the grid and 150 volts on the plate. This represents a change of $(150-120)$ or 30 volts in plate potential, and $(10-6.5)$ or 3.5 volts in grid potential. While the plate potential changed by 30 volts, the grid bias changed only by 3.5 volts. The 3.5-volt change in grid bias requires, therefore, a change in plate potential of 30 volts in order to maintain the plate current constant, or to compensate for the grid-bias change, which is relatively small. In this case, the amplification factor is $30 \div 3.5 = 8.5$. Thus, a change on the grid of 1 volt, for example, will produce as much effect on the plate current as a plate-potential change of 8.5 volts.

30. Amplification-Factor Formula.—The amplification factor of a three-element tube depends on the size and spacing of the grid structure, and on the distance between the grid and plate. This may be expressed as a formula

$$\mu = \frac{2\pi d}{a \log_{\varepsilon} \frac{a}{2\pi r}}$$

in which μ = amplification factor;

$2\pi = 2 \times 3.1416 = 6.2832$;

a = spacing between grid wires, in centimeters;

d = distance between grid and plate, in centimeters;

r = radius of grid wire, in centimeters.

The amplification factor of a tube is not altered to any appreciable extent by conditions other than those specified in the foregoing formula. For example, changes in applied voltages make no appreciable change in the amplification factor, except that at low plate voltages it may decrease slightly.

PLATE RESISTANCE

31. The plate resistance causes the drop in voltage of the electron current established between the filament and plate electrodes. There is a considerable drop in voltage caused in drawing the electrons to the plate, which varies with the spacing of the elements, the operating conditions, and various other factors. In any assembled tube, however, the plate resistance is measurable and may be checked by appropriate test methods. In specifying the plate resistance of a tube the test conditions or potentials should be specified. The plate resistance causes a voltage drop or loss in the tube which acts to all intents and purposes like a resistance, hence the name.

32. The plate resistance of a tube may be readily calculated from the characteristic curves. The plate-current characteristic data given in Fig. 8 are suitable. The plate resistance may be secured at 90 volts plate potential, for example, by taking plate-voltage changes, an increase and a decrease of equal amounts with the grid bias of, say, −4 volts, unchanged. The plate current with 105 volts on the plate and −4 volts grid bias is 3.68 milliamperes, and with the lower plate potential of 75 volts and the same grid bias the plate current is 1.26 milliamperes. Thus, a plate-potential change from 105 to 75, or of 30, volts produces a plate-current change of 3.68 to 1.26 or 2.42 milliamperes. The plate resistance is the voltage change divided by the current change in amperes. The change of 2.42 milliamperes corresponds with a change of .00242 ampere. Thus, 30 divided by .00242 equals 12,400 ohms, approximately, which is the plate resistance with 90 volts on the plate and with a grid bias of −4 volts. Other values are obtained with different plate potentials.

33. The plate resistance may be expressed as a formula:

$$R_p = \frac{E_1 - E_2}{I_1 - I_2}$$

in which R_p = plate resistance, in ohms;
E_1 = plate potential above test point, in volts;
E_2 = plate potential below test point, in volts;
I_1 = plate current above test point, in amperes;
I_2 = plate current below test point, in amperes.

The two plate-potential points should represent values equally spaced above and below the test, or reference, conditions. In order to secure the greatest accuracy the points should be taken not too far on each side of the desired test conditions.

MUTUAL CONDUCTANCE

34. The mutual conductance is a very good measure of a tube depending on both the amplification factor and the plate resistance. It is defined as the amplification factor divided by the plate resistance. The result is expressed in a unit known as the *mho*, and in order to use whole numbers the unit *micromho*, which is equal to $\frac{1}{1,000,000}$ mho, is commonly employed.

The mutual conductance may be expressed as a formula:

$$G_m = \frac{\mu \times 1,000,000}{R_p}$$

in which G_m = mutual conductance, in micromhos;
μ = amplification factor;
R_p = plate resistance, in ohms.

For example, with the tube just considered, the amplification factor of which was found to be 8.5 and the plate resistance 12,400 ohms, the mutual conductance is

$$G_m = \frac{8.5 \times 1,000,000}{12,400} = 685 \text{ micromhos.}$$

35. In general, the higher the mutual conductance of a tube, the more efficient amplifier it is considered to be. When making comparisons it is necessary to distinguish between tubes designed for the same service and having similar characteristics. For example, one commercial radio tube designed for general use has a mutual conductance of 1,600 micromhos at 135 volts plate potential, and another tube which is designed for output service has a mutual conductance of 1,360 micromhos at the same plate potential. The latter tube, nevertheless, is capable of supplying 160 per cent. greater undistorted power output when sufficient input voltage is available and the load properly adjusted. Furthermore, since the mutual conductance depends on the plate resistance, it varies with the plate voltage, hence readings of mutual conductance are meaningless unless the voltages applied during the measurements are specified.

INTERNAL CAPACITY OF TUBES

36. The electrodes of a three-element tube form small condensers, each electrode acting as a plate. The capacity between the filament and the grid as well as between the filament and the plate is about 5 micro-microfarads, and this is usually considered negligible. The capacity between the plate and grid is somewhat larger, being on the order of 8 micro-microfarads in the general-purpose tube known as type 201-A. This capacity may introduce certain erratic actions when used in high-frequency circuits. The function of the grid is to control the flow of current in the plate circuit. If the grid element acts as a plate of a condenser and the plate element acts likewise, the two constitute a coupling unit permitting a transfer of high-frequency current from the grid circuit to the plate circuit, or from the plate circuit to the grid circuit. This feature is objectionable, for it defeats or at least minimizes the prime purpose of a tube, namely, the amplification of signals. Methods of counteracting the effects of tube capacity will be given elsewhere.

MEASUREMENT OF TUBE CHARACTERISTICS

37. Amplification Factor.—A convenient method of measuring the main characteristics of a tube is by utilizing a special type of Wheatstone or balance bridge. One such circuit, called the Van der Bijl bridge, is illustrated in Fig. 9. The tube under test is shown at *a* and has its filament potential and current controlled by the rheostat *b*. Suitable instruments may be connected in this circuit for reading the filament potential and current if these characteristics are desired. Plate potential is applied by a *B* battery of proper rating. If desired, a *C* battery may be connected in the grid circuit to provide the necessary negative grid bias.

The primary of the low-frequency transformer *c* should connect with a 1,000-cycle alternating-current source free of objectionable harmonics which would affect the accuracy of balance or reading. The fixed resistance units *d* and *e*

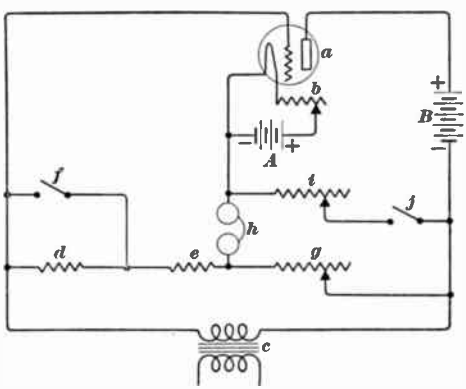


FIG. 9

should each be exactly 10 ohms, as their exactness affects the accuracy of the readings. A switch *f* short-circuits the resistance *d* for certain readings. The resistance *g* should be adjustable from 0 to 1,000 ohms in steps of 0.1 ohm. In order not to affect the accuracy of the readings, the telephone receivers *h* should have a low resistance or be connected through a suitable transformer. Another variable resistance *i* should be adjustable in 10-ohm steps from 0 to 100,000 ohms. The switch *j* connects and disconnects the resistance *i* with the test circuit.

38. The amplification factor of the tube may be secured with the switch *f* closed and the switch *j* open. The resistance g is adjusted until no signal is heard in the telephone receivers and the amplification factor is given by the formula

$$\mu = \frac{r_g}{r_e}$$

where r_g and r_e are the resistance of g and e, respectively. With e fixed at 10 ohms, as specified, the reading of g may be divided by 10 to give the actual amplification factor.

39. Plate Resistance.—The plate resistance of a tube may also be measured with the test set shown in Fig. 9, with switch f open and switch j closed. With the adjustment of resistance unchanged from the previous balance, the resistance i is varied until again no sound is heard in the telephone receivers h. With the circuit condition as specified, the reading of resistance i corresponds directly with the plate resistance, in ohms. The reading of the resistance i at balance is thus the value of the plate resistance of the tube under test.

40. Mutual Conductance.—The mutual conductance of a tube may be secured from the amplification factor and the plate resistance, as has been explained. It may also be measured by special equipment employing the change in plate current caused by a definite change in grid bias. Or, a known alternating signal may be impressed on the grid and its effect measured by a suitable meter connected with a transformer of proper impedance included in the plate circuit.

41. Interelectrode Capacity.—The measurement of the interelectrode capacity of a tube may be accomplished on a bridge of suitable design. In order to give a semblance of uniformity the Institute of Radio Engineers has tentatively proposed two methods, one using a conventional Wheatstone bridge circuit, and the other a special substitution method. The bridge specifies the connection of the tube with the plate and filament connected across the telephone receiver part of the circuit, and the grid connected to the corner of the bridge so that the desired capacity may be measured by the balance method at audio frequency. The substitution method employs a calibrated condenser whose capacity is substituted for that of the tube to restore the reading of a radio frequency output meter to the value secured with the tube under test. Since radio-frequency coupling must be guarded against, shielding should be used carefully in the latter case. In both systems a uniform and specified mounting of the tube is essential for accurate results.

USE OF RADIO TUBES

RADIO TUBES AS AUDIO AMPLIFIERS

42. Actual Amplification of Radio Tubes.—The three-element tube is used as an amplifier, a detector, an oscillator, a modulator, and a regulator. As an amplifier the tube can be used for voltage, current, or power amplification. Of these uses, only voltage and power amplification are of importance in broadcast reception.

When using the three-element tube as an amplifier, some way must be found of utilizing the output of the tube. In the case of radio-receiving sets, the output may be used to operate a sound reproducer, or to excite an additional tube to obtain further amplification. The device that is placed in the plate circuit to use the output of a tube is called the *load*. It may be in the form of a resistance, or it may be an impedance, as, for example, the primary of a transformer, a choke coil, or the windings of a sound reproducer.

43. A load in the plate circuit of a radio tube has a tendency to decrease the steepness of the plate characteristic curve. This is shown graphically in Fig. 10. At *A* is shown the characteristic plate-current curve of a well-known radio tube, with 135 volts plate potential, and no load in the plate circuit. At *B* is the characteristic curve of the same tube with the same plate potential of 135 volts, but with a resistance load in the plate circuit of 10,000 ohms. Curve *C* indicates the plate current condition with a resistance of 50,000 ohms in the plate circuit; curve *D*, 100,000 ohms; and curve *E*, 200,000 ohms. This shows that the theoretical amplification of a tube is realized only with no load in the plate circuit. Any load will tend to lower the theoretical amplification, and the output voltage will not be exactly the product of the grid voltage multiplied by the amplification factor, but of a somewhat lower magnitude.

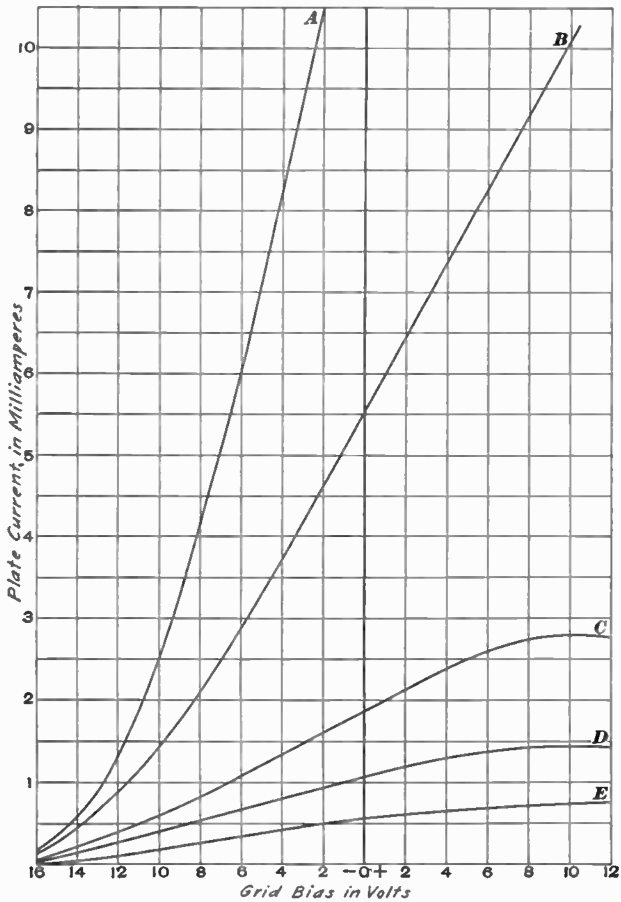


Fig. 10

44. Fundamental Circuit of Audio Amplifier.—In Fig. 11 is shown a schematic diagram of a three-element tube with its circuits connected to act as a low-frequency voltage amplifier. The low-frequency generator *a* is connected to the primary winding of the transformer *b*. The generator voltages take the place of voltages at sound frequencies. The voltages induced in the secondary winding will be alter-

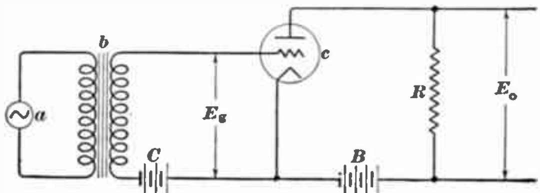


FIG. 11

nating and these are impressed on the grid-filament circuit of the amplifier tube. The filament, or *A*, battery is not shown, as the filament supply may be either d-c or a-c; a connection from the filament to the plate and grid circuits is indicated.

45. A *C*, or grid-bias, battery, Fig. 11, is included in the grid circuit. The purpose of this battery is to shift the signal

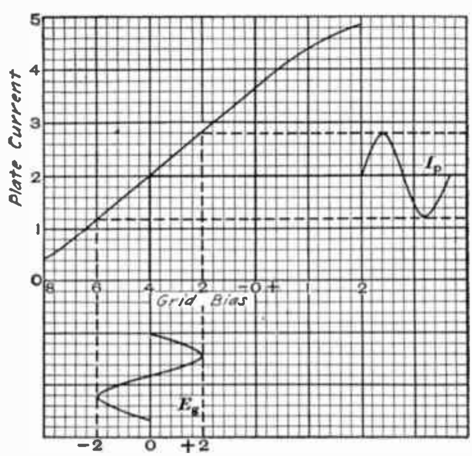


FIG. 12

voltage to the most advantageous position on the tube's characteristic curve. Reference to Fig. 12 will clear this statement. The signal voltage E_g is shown impressed on

−4 volts grid bias. The signal voltage does not exceed 2 volts, positive or negative, so the grid voltage in this case varies between −6 and −2 volts. It does not, under the circumstances, become positive. This is another reason for using a *C* battery, namely, to prevent the grid from becoming at any time positive and drawing to itself some of the electrons that should go to the plate. The function of the grid circuit is to control the current in the plate circuit, and the higher the impedance of the grid circuit, the more efficient the tube is as an amplifier. Maximum efficiency is obtained when the impedance is so high that no current flows in the grid circuit, and this condition is attained when the grid is at all times negative with reference to the filament and attracts no electrons to itself, but simply regulates their flow to the plate.

46. In Fig. 11, when no a-c voltage is impressed on the grid circuit, the voltage on the grid is that of the *C* battery. A slow-motion view of the a-c voltage impressed on the grid bias may be had by referring again to Fig. 12. The signal voltage is impressed at the point where the −4 volt grid-bias line cuts the plate-current curve. The signal voltage E_g is alternating in character. It swings first from its zero position (corresponding to −4 volts grid bias) to +2 volts maximum (−2 volts grid bias), back to zero (−4 volts grid bias), −2 volts (−6 volts grid bias) and then to zero (−4 volts grid bias). The signal voltage, therefore, alternately decreases and increases the grid bias, by adding to or subtracting from it. The net result is the same as though the biasing voltage were actually decreased and increased. This combination of grid bias and signal voltage constitutes the grid voltage E_g. Since the steady biasing voltage serves no purpose other than improving the characteristic of the tube, it is usually ignored, and the variable signal voltage is generally considered as the grid voltage.

47. The grid-voltage E_g, Fig. 11, alternately increases and decreases the electron flow within the tube, which results in a variation of plate current. According to Fig. 12, when the signal voltage is zero, −4 volts grid bias is active in the grid circuit. The normal plate current is 2 milliamperes. As the grid voltage swings in a positive direction (or less negative) the plate current increases, and becomes 2.8 milliamperes at maximum positive value of the signal. The plate current follows the signal voltage to its maximum negative value, where it becomes 1.2 milliamperes and again rises as the grid becomes less negative. The plate-current curve is shown at I_p, and resembles in outline the grid-voltage curve.

48. The resistance R, Fig. 11, serves as a means of utilizing the output of the tube c. The voltage E_o developed across this resistance is the product of the ohmic resistance R and the current I flowing through it. This follows Ohm's law, where $E=IR$. Suppose the resistance R is 15,000 ohms, and the current varies in it as shown at I_p, Fig. 12. The voltage developed across the resistance will follow the variations of current, starting from 30 volts $\left(\frac{2}{1{,}000}\times 15{,}000\right)$, gradually rising to 42 volts $\left(\frac{2.8}{1{,}000}\times 15{,}000\right)$, then falling back to 30 volts and a minimum of 18 volts $\left(\frac{1.2}{1{,}000}\times 15{,}000\right)$, and again rising to 30 volts. For the grid voltage variation from -6 to -2 volts, or a change of 4 volts, the output voltage varies from 18 to 42 volts, or a change of 24 volts. An input of 4 volts therefore produces an output of 24 volts, or 6 volts output for 1 volt input. The output voltage E_o, Fig. 11, may be utilized as the input to another tube to obtain still further amplification.

49. D-C and Signal Voltage.—From the foregoing discussion one may deduce that neither the grid-bias voltage nor the plate voltage in themselves constitute the signal. The grid-bias voltage simply changes the operating characteristics of the tube. The plate voltage supplies the necessary conveyance for the signal. The signal itself, however, is of an alternating nature. In the grid circuit it appears superimposed on an existing voltage that is negative with reference to the grid. In the plate circuit the signal appears in an enlarged form superimposed on the steady component, which is positive with reference to the plate. Neglecting the grid-bias and plate voltage, Fig. 12, it is found that the signal or grid voltage is alternating and varies from 0 to 2 volts, positive and negative. Similarly the signal voltage in the plate circuit with a 15,000-ohm load, may be considered to vary from 0 (normal plate current corresponding to 2 milliamperes) to 12 volts, positive and negative.

50. Calculation of Output Voltage.—When an a-c voltage E_g is impressed on the grid of an amplifier tube, the current in the plate circuit will vary in accordance with the variations in grid voltage. The plate current may be considered as consisting of the normal steady plate current upon which is imposed an alternating current. The steady-current component is of no value for amplification purposes, since the signaling currents do not possess steady components to be amplified; hence it is necessary to consider only the a-c component of the plate current.

The amount of amplification available from a vacuum-tube circuit depends on the amplification factor of the tube and on the load introduced in the plate circuit. With a non-inductive resistance R, Fig. 11, in the plate circuit, the total plate-circuit resistance is R_p+R, in which R_p is the internal plate resistance of the tube and R the external load resistance. The a-c component I_p (plate current) set up by an a-c voltage E_g in the grid circuit may be determined by the equation

$$I_p=\frac{\mu E_g}{R_p+R} \qquad (1)$$

This a-c plate current I_p flowing through the resistance R gives an output voltage E_o, which may be determined as follows:

$$E_o=I_pR=\mu E_g\frac{R}{R_p+R} \qquad (2)$$

With a pure resistance load, no matter how complex in shape the input potential may be, the output will have exactly the same shape but will be of greater magnitude. This is called distortionless amplification and is very useful when frequencies of widely different values are present in the input voltage and must be amplified, or reproduced in enlarged form, without discrimination.

51. Tubes Under Inductive Load.—If instead of a resistance R, Fig. 12, an inductance coil is used in the plate circuit of the tube, the output voltage E_o will depend not only on the magnitude of the grid voltage but also on its frequency. If the resistance of the coil is high compared with its reactance, the discrimination toward certain frequencies is lessened, and the amplification approaches that obtained with a resistance load.

The inductive reactance of a coil may be determined by the equation

$$X_s = 2\pi f L \qquad (1)$$

in which X_s = inductive reactance, in ohms;
$\pi = 3.1416$;
f = frequency, in cycles;
L = inductance, in henrys.

In a circuit in which both inductance and capacity are present, the total reactance is the algebraic sum of the individual reactances; thus,

$$X = 2\pi f L - \frac{1}{2\pi f C} \qquad (2)$$

in which X = total reactance, in ohms;
C = capacity, in farads.

52. The current in the plate circuit of a tube having a reactance load, may be determined by the equation

$$I_p = \sqrt{(R_p+R)^2+X^2} \qquad (1)$$

The output potential in the external circuit is as follows:

$$E_o = I_p Z = \mu E_g \frac{\sqrt{R^2+X^2}}{\sqrt{(R_p+R)^2+X^2}} \qquad (2)$$

in which E_o = output voltage, in volts;
I_p = plate current, in amperes;
Z = impedance of external circuit $\sqrt{R^2+X^2}$;
R = resistance of external circuit, in ohms;
μ = amplification factor of tube;
R_p = internal plate resistance, in ohms.

The foregoing equations prove conclusively that the output voltage of an amplifier having a reactance load varies under different frequency conditions. Unless sufficient resistance is introduced into the plate circuit, amplification of widely different frequencies will be uneven and distortion will result. This applies to a load consisting of a simple inductance coil as well as to a transformer, the primary winding of which is in the plate circuit of one tube, and the secondary in the grid circuit of the next tube.

RADIO-FREQUENCY AMPLIFIER

53. In radio-frequency receiving-set circuits the operation of the tube is practically the same as in low- or audio-frequency circuits. The radio-frequency circuits are adjusted to select the desired frequency and the tube amplifies the signal at radio frequency. The tuning circuits consist of coils and condensers which may be adjusted to select signals at any frequency within their range. The signal energy to be amplified is received from a pick-up circuit, such as the antenna system of a receiving set. After being amplified successively by two or more radio tubes, the enlarged signal is passed on to the detector tube, which separates the audio-frequency signal from the radio-frequency component. The audio-frequency signal then goes to the audio amplifier, or sound reproducer.

The radio-frequency amplifier stages of transmitting sets operate with positive grid swings and in this and other respects are quite like the radio-frequency oscillator service described elsewhere.

DETECTOR ACTION

54. Function of Detector.—The function of a detector tube in a receiving system is to release the signal from the high-frequency carrier. Transmission of signals by radio can take place only at frequencies above audibility. It is necessary, therefore, to use high-frequency currents in transmission, and to drop the high-frequency in reception.

The three-element radio tube can be made to act as a very efficient detector. In one system of detection, a small-capacity condenser shunted by a high-resistance leak forms part of the grid circuit. In another system the tube is so biased that amplification can take place only near the bend of its characteristic curve. Both these systems are used very extensively.

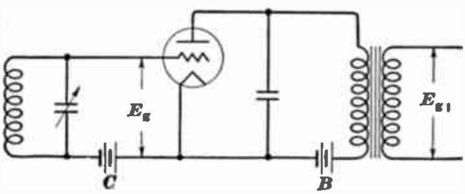


FIG. 13

55. Grid-Bias Detection.—A radio-tube circuit arranged for grid-bias detection is shown in Fig. 13. The plate voltage and grid bias are so chosen that the tube operates on the lower bend of its characteristic curve. This means that the tube will amplify more the positive sections of voltage on the grid than it will the negative.

Reference may now be made to Fig. 14, which shows the detection curves. The biasing battery reduces the zero position of the grid-voltage curve E_g to some negative value, and with the plate voltage adjusted so that the amplification takes place only on the positive half-cycles, the plate current will be like that shown at I_p. The average of the plate current above the normal plate-current line represents the audio-frequency component and this is indicated by the dotted line. The action of the high-inductance primary of the audio transformer practically suppresses the individual radio-frequency pulsations and gives the current represented by the dotted curve. The action of the by-pass condenser across the primary is to provide a path for the radio-frequency impulses, permitting only the audio-frequency component to pass through the primary winding.

The voltage induced in the secondary winding of the audio-frequency transformer will be like that shown at E_{g1}. As the average current I_p is increasing, the voltage E_{g1} is decreasing. When this current reaches a certain normal stage, the secondary

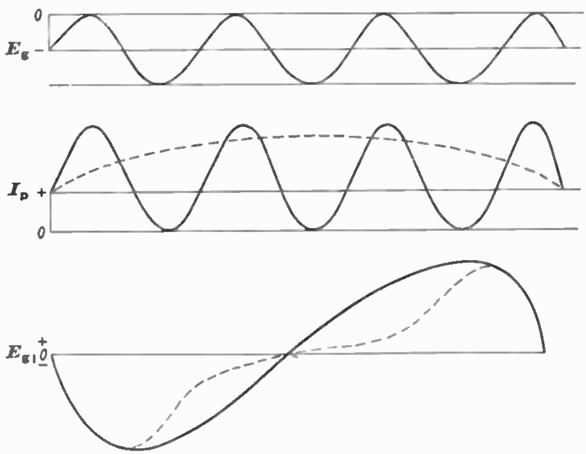


Fig. 14

current reaches zero, and again goes to maximum positive when the average plate current suddenly reaches zero.

The foregoing shows how the detector tube changes a number of radio-frequency pulses into a single audio-impulse. The voltage in the secondary winding is in reality more like that shown by the dotted outline at E_{g1}, which portrays the effect of the second harmonic. For all practical purposes, however, the smooth curve may be considered as being representative of the secondary voltage.

56. Grid-Leak Detection.—A radio tube arranged for grid leak detection is shown in Fig. 15. The voltage introduced into the grid circuit is like that shown at E_g, Fig. 16. During the first positive impulse on the grid, the grid attracts

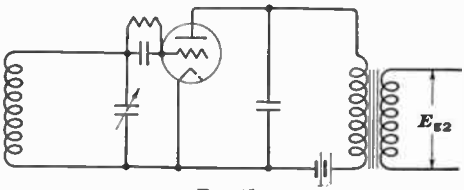


Fig. 15

a few electrons which, because of the presence of the grid condenser, cannot return to the filament and consequently give the grid a slight negative charge. During the following positive pulses, the number of negative electrons on the grid increases, so that the signal acts as though a gradually increas-

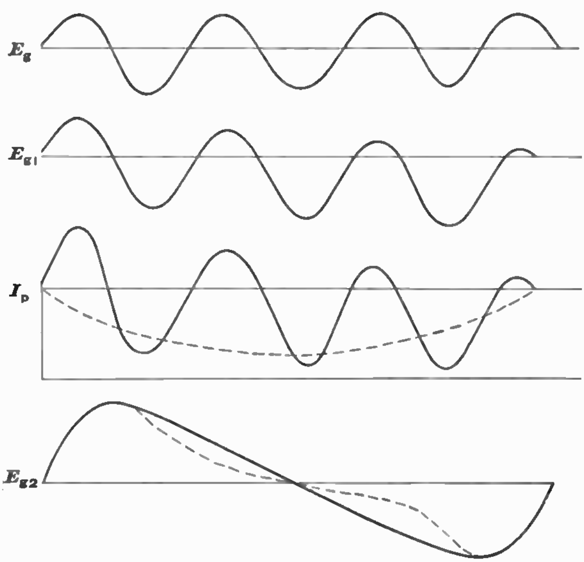


Fig. 16

ing negative bias were placed on the grid. The actual voltage on the grid will, therefore, appear like that shown at E_{g1}, Fig. 16. The plate current I_p will follow the variations in the signal voltage and also the increasing bias, so that the plate current will show a general tendency to decrease. The average plate current shown by the dotted line represents the audio-frequency component. The voltage across the terminals of the secondary winding is shown at E_{g2}.

The grid-leak method is more sensitive than bias detection, and to this extent is better when the input voltages are small, although overloading will occur more readily than with the grid-bias method. When the input voltage is large, bias detection may be used to take full advantage of the greater output available and of the freedom from distortion that results from overloading. The tube impedance is rather high with grid-bias detection so that the first audio transformer should have a high-inductance primary.

The grid return for the high-vacuum tubes should connect with the positive filament terminal in order to secure as high a normal positive bias as possible. For the gas-filled or gas type of detector tubes the grid return should connect with the negative filament terminal, although satisfactory operation should be secured with this connection made to the positive filament terminal. Tubes with high values of amplification factor tend to give greater amplifier action along with the usual detector action and are preferable to the general-purpose tubes.

RADIO-FREQUENCY OSCILLATOR

57. The usual radio-frequency oscillator is really a special adaptation of the radio-frequency amplifier, the main difference being that the oscillator supplies its own grid excitation by the withdrawal of a sufficient amount of energy from the output circuit. The tube therefore acts as a generator of high-frequency currents. The grid inductance coil is ordinarily coupled with the plate circuit either by an inductance coil or by a condenser, so that the feed-back of energy to the grid is enough at least to sustain oscillations by overcoming the tube output, including any useful load and the internal losses as an amplifier. The excitation is so strong that the grid is driven positive to a considerable extent with each audio-frequency pulsation. The grid bias is so high that the plate current would be cut off or reduced to zero with no excitation.

The oscillator tube usually secures its grid bias by means of a grid condenser and leak. This method more or less automatically takes care of providing the correct grid bias, whose value is not critical. Also, the negative grid bias may be provided by a separate potential supply, or a combination of the two methods is very effective. The power taken by the grid of the oscillator tube from the output circuit is usually not large, and very high over-all efficiencies are possible. The oscillator action is essentially the same for any of the three electrode types of tubes, with the natural features applicable to the various types of circuits and services.

MODULATOR SERVICE

58. The three-electrode tube may be advantageously used as a modulator in the constant-current or Heising system. In this service the modulator tube acts chiefly as an audio-frequency amplifier, and instead of delivering audio-frequency energy in the usual form, acts to mould or modulate the energy produced by a radio-frequency amplifier or oscillator. This is accomplished, briefly, by increasing and decreasing the amplitude of the radio-frequency carrier wave in accord with the excitation supplied to the grid of the modulator tube.

The circuit of a modulated transmitter is indicated schematically in Fig. 17. The course of the audio-frequency signal starts with the microphone *a* energized by its local battery *b*. The audio-frequency transformer *c* applies the pulsations on the grid of the modulator tube *d* with its filament-supply battery *A* and grid-bias battery *C*. The plate-supply battery, rectifier, or generator *B* provides plate potential for the modulator tube *d* and the power-amplifier tube *e* through a large audio-frequency choke coil *f*. A radio-frequency choke coil *g* prevents the radio-frequency energy associated with tube *e* from passing to affect tube *d* or its auxiliaries. Tube *e* may be connected as a self-excited oscillator, or, as is shown here, its grid may receive radio-frequency excitation from a crystal-controlled master oscillator tube *h*. The modulated radio-frequency output is transferred to the antenna by suitable coupling transformer and radiated.

59. Audio-frequency voice or music changes impressed electrically on the grid of tube *d*, Fig. 17, vary its plate current in a corresponding manner. Any increase in the plate current must be at the expense of the plate current taken by tube *e* while a decrease in plate current of tube *d* forces that much more to tube *e*, since the choke coil *f* acts to keep the total plate current taken by tubes *d* and *e* constant. Actually,

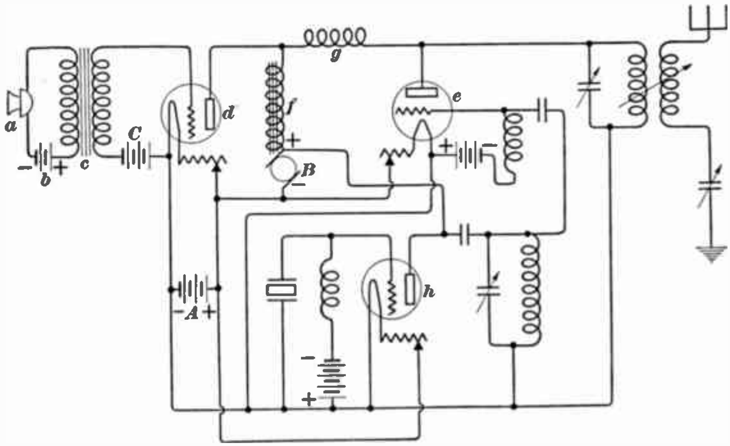


FIG. 17

the current changes enough to produce a potential across the tube *e* suitable to require it to follow these changes. The radio-frequency output energy from tube *e* is therefore modulated in accord with the desired voice or music.

Other methods of modulation are used only infrequently. For example, the grid of the radio-frequency output or oscillator tube may be modulated directly by the desired audio frequency. This is not very practicable, as it is subject to a considerable amount of distortion even with moderate amounts of power. This method should not be confused with the practice, occasionally used, of amplifying the radio-frequency signal, which has already been modulated and carries the desired audio-frequency components. Frequency modulation is accomplished by varying the frequency of the radio-frequency carrier wave in accord with the desired audio-frequency signal.

ABSORBER SERVICE

60. The three-electrode tube may be used as an absorber of electrical energy, although its individual part may be more nearly that of a valve. As an absorber the tube operates in connection with a series plate resistance as a valve or gate, and, by grid-bias changes, controls the plate current flowing through the tube. In this manner the absorber tube may take the output from a rectifier system as needed, thereby keeping its load and regulation constant and permitting of exceedingly constant operation of the set and rectifier by removing injurious transient conditions.

FOUR-ELECTRODE TUBES

SPACE-CHARGE OPERATION

61. Four-electrode tubes, as the name implies, have four active electrodes each with an essential contributing effect on the others. The tube possesses the usual filament, or cathode, and plate, with two intervening grid structures. One of these grids is employed as in the three-electrode tube to control the plate current, whereas the other may be connected to reduce either the space-charge effect or the inter-electrode capacity between the plate and control grid.

The space-charge grid must be the one next to the filament so that it may be as near as possible to the space charge field to produce a neutralizing or at least a controlling effect. For this purpose it should have a bias slightly positive with respect to the filament. The control grid will then have the usual negative bias and operate to change the plate current in quite the conventional manner. The function of the space-charge grid is chiefly to increase the plate current over the value it would have were that grid not present, the amount of increase depending roughly on the amount of the space-charge grid bias. Very little practical use has been made of this type of tube in commercial receiving sets, although it is very interesting in experimental work and excellent results have already been obtained.

SCREEN-GRID OPERATION

62. The other chief use of the four-electrode tube is with the outer grid employed as an electrostatic shield between the inner or control grid and the plate. In this manner the tendency for the output or plate circuit to feed energy back into the grid or input circuit through the plate to grid capacity is practically removed. The need for careful neutralizing is thereby eliminated, except that care must be taken to prevent feed-back coupling between the external plate and grid tuned circuits. For this purpose the screen must be designed so as to shield the control grid electrically from the plate as effectively as possible. The plate or control-grid leads, or both, are brought out of opposite ends of the tube to aid connection with suitable circuits without introducing undue coupling between these circuits.

63. Owing to the screening effect the attraction of the plate is reduced and the plate current in this type of tube is low. Also, the spacing of the active electrodes is greater than would otherwise be the case. These various effects produce a relatively high amplification factor and also a very high plate resistance. Since such characteristics are necessary these tubes are adapted almost exclusively to radio-frequency amplifier operation. Since the feed-back capacity is so low, tubes may be replaced without the necessity for reneutralizing the set, which is otherwise true of high-frequency or short-wave transmitters. The screen operates with positive potentials of, roughly, one-sixth of the plate potential. This may be secured from a separate source, a potentiometer from the plate supply, or a series resistance in a lead from the plate potential.

COMMERCIAL RADIO TUBES

RECEIVING TUBES

EARLY DEVELOPMENTS

64. The earliest types of three-electrode tubes as well as many of the present types are what might be called general-purpose tubes as distinct from those designed chiefly for special fields of service. The high development of radio receivers has required special tubes in order to secure the desired operating characteristics. Even in the general-purpose class several tubes have been developed to meet the changed requirements and refinements. The earlier types used tungsten filaments, which, due to the large current, required storage-battery supply, such as the early radiotron UV-201. A later tube, the WD-11, used an oxide-coated filament which, with a 1-volt, 0.25 ampere filament rating, could be economically operated from dry cells. The later designs of WD-12 and WX-12 are designed to employ the old bayonet-type base and the new standard UX base, respectively.

TYPE 201-A

65. The development of the thoriated filament occasioned the UV-201-A with a filament rating of 5 volts at 0.25 ampere, thus giving very economical storage-battery operation. With the advance of receiver design came the UX or push type of base, hence the change in type number to UX-201-A, as illustrated in Fig. 18. The detailed important electrical and mechanical characteristics are listed elsewhere. Similar tubes made by other manufacturers usually have the 01-A as part of the style number with their distinctive letters as a prefix, such as CX-301A (Cunningham) and AX (Ceco).

The parts of the tube and its assembly sequence are of importance. The central glass portion, called the *press*, is made from tubular glass. The desired lead wires and exhaust tube are placed in position and the upper portion heated and flattened to form the press. The exhaust tube is blown open so as to form a channel through which the tube may later be exhausted. The function of the lead and support wires are self-explanatory. However, care must be exercised to use lead-in wire material that has the same coefficient of expansion as glass. If this wire expands at too rapid a rate when heated, it will crack the glass, and if too slow it will permit a space to form between the glass and metal, admitting air. The wires are cut to the proper lengths and formed to hold the various elements. These parts are made separately and mounted by means of special equipment or jigs to give the proper adjustment and spacing of elements. The parts are spot-welded in position to form a unit structure. The whole central assembly, called the mount, is carefully inspected to assure proper alinement of all parts. The bulb is placed over the mount, then heated and sealed on to the flared-out section on the lower end of the stem.

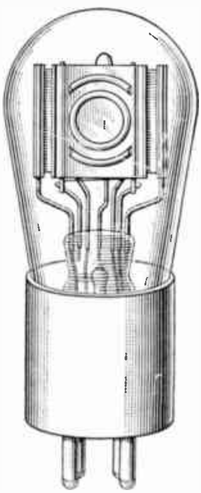


FIG. 18

66. The tube is next connected with an exhaust pump, which draws out the free gases to a very high degree of exhaustion. The parts, including the bulb, are heated so as to drive out as much of the gas in these parts as possible. After a good degree of exhaust has been secured the plate and other parts are heated to a high temperature by radio-frequency currents induced from a surrounding coil. This heats the metal parts enough to drive out the gas so it can be pumped out of the tube. This operation also heats the getter material, which, at the high temperature, vaporizes and combines with the remaining gas to form a deposit on the relatively cool interior of the bulb. With some getter materials, such as magnesium, this deposit is quite silvery in appearance. The tube is then

sealed off, which makes it air-tight. It is then based and given such seasoning treatment as is necessary to render the filament active and accomplish clean-up of any residual gas. The tube is then carefully tested and securely packed.

TYPE 199

67. The UV-199 and the UX-199 tubes with special UV and UX bases, respectively, were designed for service in receiving sets for filament operation from dry batteries. The thoriated type of filament operates at 3.3 volts, with a current drain of 0.063 ampere. The electrical characteristics, as enumerated elsewhere, adapt this tube to general receiving-set uses. This tube is known also as C-299 and C-X299 (Cunningham) and B, BX, and C (Ceco).

TYPE 226

68. Another general-purpose tube, but one which is designed to operate directly from an alternating-current supply system, is called the UX-226. Other designations are CX-326 (Cunningham) and M-26 (Ceco). It is not far different from the UX-201-A, except that the filament voltage of the UX-226 has been kept low in order that the reversals of a-c potential on the filament will have as little effect as possible on the operation of the tube. This particular tube is not suitable for use as a detector when operated from alternating current, as it will produce an objectionable amount of hum.

TYPE 227

69. A general-purpose tube of special design for operation directly from alternating current of the proper potential is called the UY-227 and is shown in Fig. 19. This tube is also known as C-327 (Cunningham) and N-27 (Ceco). The emitter, or cathode, electrode is a sleeve or cylinder with an oxide coating as the active material. A filament, which acts slowly as a heater, is mounted inside the cathode, and is electrically insulated therefrom. The cylindrical grid and plate structures surround the cathode in the conventional manner. On account of the extra lead required by the cathode, the tube is equipped with a special type of 5-pin base as is designated by the UY prefix letters. Since none of the alternating-current energy can reach the cathode this type of tube may be used in any socket in the set, including the critical detector position. The special operating conditions and circuit connections and voltages recommended by the manufacturer should be followed in the operation of this tube as well as with the other types.

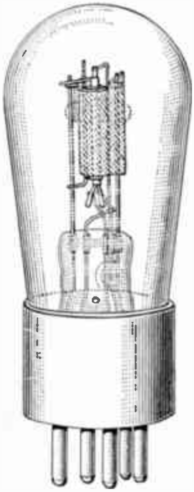


Fig. 19

TYPE 200-A DETECTOR

70. One of the early special types of tubes was the UV-200, which was a soft or gas-type detector, as compared with the high vacuum of most other types. It operated on the extreme sensitivity produced by the gas at certain critical plate potentials. This tube was followed by the caesium content tube, called the UX-200-A, known also as CX-300A (Cunningham), and H (Ceco), whose high degree of sensitivity is not critical with respect to plate potential. This tube in addition has a high amplification factor in order to make the detector action as sensitive as possible.

TYPE 240

71. For use with resistance-coupled amplifiers where the nature of the coupling device requires a high series plate resistance with a consequent low plate current, it is advisable to use a tube that will operate well under these conditions. Also, there is no gain in amplification in the coupling resistances of most resistance-coupled amplifiers, practically all gain being secured in the tubes. A tube with a high amplification factor as well as a high internal plate resistance, serves particularly well in this service with its accompanying ability to operate on a low plate current. The UX-240, CX-340, or G radio tube was designed to fit this service with an amplification factor of 30. This tube is also suitable for use as a detector in practically any of the storage battery operated receivers.

TYPE 120

72. A special output tube, which has a 3.3-volt filament for operation in parallel from the filament supply of UX-199 tubes, is known as radiotron UX-120, CX-220, or E. The filament size and consequently the current is somewhat larger than in type 199 so as to supply the larger plate-current requirements. The UX-120 has a low amplification factor and consequently requires a rather high negative grid bias, thus permitting of a relatively strong grid excitation, or swing. The plate output resistance is also low with an accompanying large plate current. The plate-current changes therefore represent a considerable amount of undistorted power such as is desirable for loud-speaker operation. The fact that the amplification factor is low is not generally objectionable, as it may be compensated for in the preceding stages, where overloading normally is not so apt to occur.

TYPE 112-A

73. The UX-112 tube with a half-ampere filament and the more recent UX-112-A, CX-112A, and F-12-A tube with a one-quarter ampere filament are of the storage-battery class with 5-volt filaments. While called a general-purpose class of tube, each has had considerable application as an output tube, particularly where the power requirements were moderate, and where the normal amplification factor of 8 was useful. This type of tube has an oxide-coated filament, which operates at a dull reddish color.

TYPE 171-A

74. The UX-171-A, CX-371A, and J-71-A tube likewise operates with a five-volt battery or transformer supply for the filament. This tube also has an oxide-coated filament. Owing to the design it operates with a quite high plate potential and with accompanying large values of negative grid bias. The amplification factor is low as is also the internal plate resistance. The plate current is quite large, making it preferable to use a coupling transformer or other device so that the plate current will not flow through the loud speaker and cause overheating or other trouble in the windings. This tube is designed for use in the last audio or output stage of a receiver or in other similar amplifications.

It is entirely possible to operate the filament of the last audio-frequency amplifier tube directly from an alternating-current source without the introduction of an objectionable a-c hum, hence this is often practiced. Push-pull or parallel operation of two tubes is practicable in case of plate-voltage limitations or where more power is required than one tube can deliver. The earlier UX-171 tube had a ½-ampere filament, whereas the UX-171-A has an oxide-coated filament requiring but ¼ ampere.

TYPE 210

75. The plate current, particularly if large, requires a filament source of considerable size and a plate able to dissipate the energy produced at that place. If the plate current is sufficiently large and the potential high the plate must have a special design. The radiotron UX-210, CX-310, and L-10 has a plate of such size that the tube, operating at moderate voltages, is often classed as a small transmitting tube. With a moderate amplification factor of 8 and other desirable design features, the tube is able to deliver a considerable undistorted audio output. This tube has a rather large filament made of a special thoriated wire specially treated during manufacture. At 7.5 volts the filament current requirement is 1.25 amperes. Owing to the large plate current and the high plate potential, a transformer or other means of coupling must be used between this tube and the loud speaker.

TYPE 250

76. The radiotron designated as UX-250, CX-350, and L-50 has an oxide-coated filament designed for this special type of service as an audio-frequency output or power tube. The amplification-constant and plate-resistance values are quite low. This results in a large plate current necessitating a plate structure of special design to dissipate the large amount of heat that is produced. However, the characteristics are such that a very large amount of undistorted power output may be secured from a single tube. The UX-250 has a filament current rating of 1.25 amperes at a filament potential of 7.5 volts, and is generally operated directly from the alternating-current supply lines. As in the cases of the other output tubes a coupling transformer is necessary between the plate circuit and the loud speaker.

TYPE 245

77. The UX-245 is an audio-frequency output tube designed with a filament potential of 2.5 volts so as to operate in parallel with the usual types of alternating-current tubes. The amplification factor and other electrical characteristics have been so selected as to make the tube suitable for use as a last audio-frequency amplifier tube with rather large grid swings, but with moderate plate potentials. The filament is of the oxide-coated type.

SCREEN-GRID TUBES

78. The UX-222 radiotron is a commercial receiving tube of the four-electrode type. The screen grid nearly encloses the plate and control grid as well as the filament. The screen grid connects with the usual grid pin in the base, and the control-grid lead is brought out of the top of the bulb and terminates in a small cap to which a clip connection may easily be made. Owing to the special operating features of this tube the manufacturer's recommendations should be carefully followed.

Type UX-222 is of the filament type and is generally used in battery-operated sets. Type UY-224 is of the indirectly heated cathode type and is employed in a-c operated sets.

RECTIFIER TUBES

79. Types 280.—Radiotron UX-280 is full-wave rectifier and is employed in plate-supply units especially designed for it. This tube has two separate plates with filaments in parallel, one located inside each plate. The filaments of this tube are of the oxide-coated type. Owing to difficulties in construction which would entail considerable expense, the full-wave type of rectifier tube is made only for very low voltage service. The tube could also be constructed with two separate filaments and one common plate system, each section made to act upon one of the filaments.

80. Type 281.—The UX-281 radiotron also employs the oxide-coated type of filament and operates at voltages considerably higher than are recommended for the previous type. The UX-281 is often used with suitable circuits and auxiliaries to supply plate potential for the higher voltage types of power-output tubes used in radio receivers. It is a half-wave type, and two tubes are necessary to secure full-wave rectification.

81. Hot-Cathode Mercury-Vapor Rectifier Tubes.—A larger type of rectifier tube, which is of the half-wave type in that it has a single plate and filament, is called radiotron UX-866. Here, too, the filament is oxide-coated and arranged in an inverted **V** form for purposes of rigidity and convenience of design. The plate has a disk shape and connects with a small cap on the top of the bulb. Owing to the mercury in the tube it is called a hot-cathode mercury-vapor rectifier.

Mercury is introduced into this type of tube during manufacture and produces a mercury vapor or free gas atoms of mercury. When the filament is lighted, electrons are liberated in the usual manner, which, under the influence of a plate potential, collide with the atoms to produce ionization of the mercury. This ionization liberates a large number of free electrons which augment the current between the filament and plate. The ionization in the tube produces a considerable and characteristic bluish glow in the tube when it is in operation. The potential drop between the filament and plate or anode is very low. This is a true mercury-vapor drop, and is generally well below 15 volts. Even with a considerable rectified current the loss of energy in the tube, and consequently the plate heating, is very low.

82. This general type of tube is also made in several higher ratings for the heavier types of service. The plate may take the form of a metal disk, or it may be a form of carbon button. The plate electrode connects with a cap on the bulb at the end opposite to the filament leads or base. The oxide-coated filament in each type is made in a size proportional to the rating of the tube. The design is such that the tubes should be operated only with the filament end down.

The hot-cathode mercury-vapor as well as the other rectifier tubes are best rated as to the peak inverse plate potential and peak plate-current values which they will stand. The peak inverse plate potential is the maximum potential the tube will stand in an inverse direction without danger of internal arcing between the elements. The inverse plate potential is the voltage with the plate negative and the filament positive as occurs during part of each cycle. The peak plate current refers to the absolute maximum value of plate current that can be safely drawn from the filament.

REGULATOR TUBES

83. Type 876.—A one-electrode tube, or one that has a single principal electrode or operating element, has certain special and limited applications. Practically, the most important one is a filament type of tube in which the filament or cathode element acts in a regulatory or control capacity. The filament is constructed of such a material that, in the presence of a suitable gas, the desired characteristics may be obtained. For regulation or control purposes the voltage drop across the tube should be moderate, and should change by a relatively large degree as the filament current is changed by only a small amount.

One commercial type of tube which makes use of this principle is shown in Fig. 20 and is called by the trade name of radiotron UV-876. The tube is mounted in a mogul or large lamp base *a*. The iron filament *b* of proper size is wound over and supported by mica disks *c*. The bulb contains a hydrogen gaseous atmosphere, which assists the filament in its proper functioning. There will be an explosive mixture in case air leaks into the tube, hence it should always be operated in a ventilated can or sort of chimney. The tube is connected in series between the incoming supply energy and the transformer and thus maintains a practically constant current through itself by absorbing any increase in potential by producing a higher internal drop, or by reducing its internal drop in case the applied potential is reduced.

84. The regulator tube is designed to operate over a certain voltage range. An increase in line voltage due to any cause will increase the current, but the internal drop will be relatively increased to an extent sufficient practically to compensate for the change. Any decrease in applied voltage will reduce the current and to greater degree the internal tube drop. These effects tend to absorb any changes in impressed voltage by keeping the current practically constant, and thus produce a nearly steady voltage across the primary of the transformer in series with which it may be connected. In this manner any line-voltage variations are prevented from affecting the operation of the radio set, except to a very limited degree.

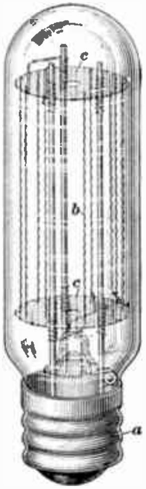


Fig. 20

85. Type 874.—The conduction of a gas may be employed to give special desired characteristics. Certain gases such as argon or neon change very rapidly in resistance over a critical range of current. This property may be utilized to cause the tube to take a very small amount of energy under some conditions and a relatively large amount of energy under only slightly different conditions.

This principle is the basis of operation of radiotron UX-874. The tube has two electrodes; a cathode in the form of a large surface, and an anode in the form of a minute surface or essentially a point. A voltage applied between the two electrodes, with the anode positive, will produce a certain current. By raising the voltage a small amount the current will increase by a large amount. This feature may be used to maintain an essentially constant voltage at the terminals of a *B* battery eliminator even with a wide range of loads, or, since the action is instantaneous, with variations in the load requirements.

RAYTHEON RECTIFIER TUBE

86. Another tube using gas conduction in its operation is the Raytheon type of rectifier. The fundamental construction employs two electrodes, one representing practically a point collector, and the other possessing a relatively large surface. Owing to the spacing between electrodes and the use of a suitable gas inside the tube, the desired characteristics are secured of a tube permitting current to flow by the passage of electrons from the large surface of the cathode to the relatively minute surface of the anode. Because of the relative sizes of the electrodes, the current or electron flow in the opposite direction is insignificant. Such tubes are commonly made with double anodes for full-wave rectification and in sizes and types to meet the usual needs of radio receivers or the power-supply units for such sets.

AVERAGE CHARACTERISTICS OF RECEIVING TUBES

87. In Table I will be found the characteristics of most commercial receiving tubes. Referring, for example, to UY-227, it will be found that this tube is of the a-c heater type, and may be used either as a detector or an amplifier. The heater voltage is 2.5 volts and is obtained from a transformer. The filament current is 1.75 amperes. Further data indicate the plate and grid specifications for operation as a detector and as an amplifier.

COMMERCIAL TRANSMITTING TUBES

GENERAL

88. The transmitting tubes are so called from the fact that they are designed to handle the relatively large amounts of power required in transmitting service. They are used in radio work, chiefly in the various types of transmitters of telegraph and broadcast messages. The smaller sizes may be employed in the output stages of special high-powered audio-amplifier systems for auditorium loud-speaker work and similar applications. Some of the smaller sizes may be employed in the output stages of transmitters of moderate power, whereas in larger powered transmitters they may be used in the intermediate stages to excite the output tubes of still higher rating. The largest sizes are employed in the transmitters of high power rating. The rating is usually based on a conservative useful power output basis in radio-frequency service. The characteristics of three- and four-electrode transmitting tubes are given in Table II.

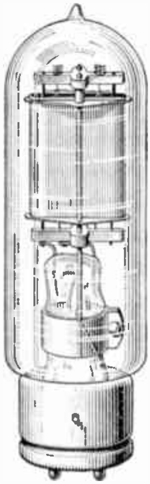


FIG. 21

50- TO 75-WATT TYPES

89. UV-203-A.—One widely used class of transmitting tube has an output rating of from 50 to 75 watts with a still higher output being easily obtainable in efficient circuits. This rating is conservative, as the tube has been improved from time to time and can easily handle these power ratings continuously. Besides the addition of fins to the plate element, its surface is treated by sand-blasting to improve the heat-radiating qualities. The tube is made with several interesting features as shown in Fig. 21. The elements are rigidly secured by the insulators, which assure proper spacing of the parts and are effective in giving rigidity to the whole assembly.

The tube is sometimes made with a rather high amplification factor and is then called the UV-203-A. As such its plate resistance is rather high, hence it is not well adapted to audio-frequency and modulator service. The UV-211 has a moderate value of amplification factor of 12, as is given in Table II, and with its moderate plate resistance is suitable for service as a general-purpose tube. The UV-845 has a relatively low amplification factor, and a consequent low plate resistance. It is therefore not well suited to radio-frequency service, but does make an excellent audio-frequency amplifier and modulator tube by virtue of its ability to amplify a relatively large signal with practically no distortion.

90. UV-845.—The UV-845 is useful in loud-speaker operation where large volume of sound is required, such as in an auditorium. Although the operating voltages are high and special transformers and other equipment are required, the general operating features are not much different from those applying to the usual receiving tubes. It is quite common practice, however, to utilize the plate-current drop through a resistance in the plate circuit to provide all or part of the grid bias. This helps to equalize the division of load between several tubes in parallel as the plate current automatically adjusts itself under these conditions. Thus, tubes which may happen to vary a little in characteristics will be equally loaded.

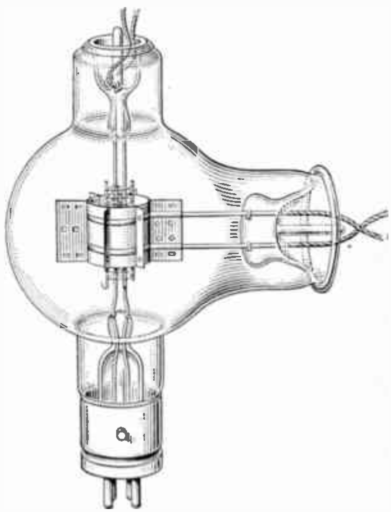


FIG. 22

75-WATT SIZE

91. A tube for high-frequency or short-wave service should possess a low capacity between elements both in order to permit of tuning to short wavelengths and to make the feed-back capacity as low as possible. The UX-852 tube was designed with this in view, and, as shown in Fig. 22, the plate and grid structures are specially supported to reduce the capacity effects between the support wires as much as possible. The high plate resistance of this tube is a safety feature in that it tends to prevent overheating of the plate by limiting the plate current to a low value in case the tube stops oscillating.

250-WATT TUBES

92. The next size of transmitting tube has a plate dissipation rating of about 250 watts, and an output somewhat greater than this value may be secured with the tube operating properly. The UV-204-A radiotron, as one type is called, is illustrated in Fig. 23. The plate lead is taken out of the tube at the end opposite the filament and grid leads, and thus is better able to stand its rated operating potentials. The tube is likewise held or secured at both ends in special sockets while in operation. The electrical characteristics are such that the tube is chiefly suited to radio-frequency service.

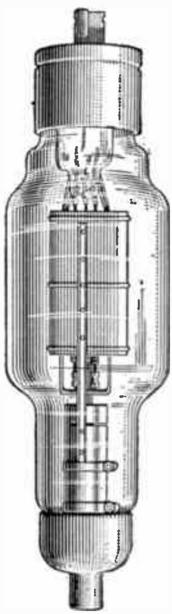


FIG. 23

A tube slightly different from the UV-204-A in electrical characteristics but possessing a tungsten filament, which is frequently an advantage, is known as the UV-853. This tube is able to stand hard usage, owing in part to the limited emission, which prevents extreme overloading, and the natural ruggedness of its tungsten filament. This tube is also chiefly suited to radio-frequency service.

400-WATT SIZE

93. The UV-849 is a tube specially designed for low-power modulator service. It is able to handle a fair amount of undistorted power, and a low internal plate resistance is secured by close spacing of the elements. Because of the unevenness of plate heating in audio-frequency amplifier and modulator service, the plate dissipation limit in such services is only 300 watts, whereas 400 watts is permitted otherwise.

1,000-WATT TRANSMITTING TUBE

94. An air-cooled tube with a large plate dissipation is frequently needed. The UV-851 tube has a particularly low plate resistance, and thus is able to operate from very moderate plate potentials. This tube has a large flat plate with very small clearances between the various elements. Here, as elsewhere, the plate heating is not as uniform under audio-frequency and modulator conditions as in radio-frequency service, owing to a tendency for the plate current and dissipation to be concentrated in local spots in the first case and the better distribution produced by the second type of service. The ratings of plate dissipation maximum values are 600 to 750 watts in audio- and radio-frequency service, respectively. Owing, also, to the low resistance of the tube, it is very apt to be seriously damaged by overload in case the grid bias fails, or if the tube stops oscillating when being used as an oscillator.

The UV-206 tube has a somewhat similar rating but is designed to operate at plate potentials as high as 15,000 volts, in case such supply is available for other tubes. This tube could thus be operated as a master oscillator, securing its plate supply from the same source as is used for the high power tubes. It is not adapted to audio-frequency service, because of its inherent high plate resistance accompanying the large element spacings required for high-voltage operation.

10-KILOWATT SIZE

95. The UV-854 radiotron is a transmitting tube with a conservative output rating of 10 kilowatts or 10,000 watts. Its maximum plate dissipation rating is 10 kilowatts, which implies a water-cooled anode as is described elsewhere. The amplification factor of 14 is such as to make it suitable for general use, and it has been widely employed in modulator, oscillator, and radio-frequency service. Although the plate dissipation is as high as that of some other water-cooled tubes, the filament emission is somewhat less owing to the lower filament wattage; hence the lower rating as regards the useful output.

20-KILOWATT TYPES

96. Another widely used water-cooled tube is radiotron UV-207, which has a maximum plate dissipation rating of 10 kilowatts, and an output rating of 20 kilowatts. The average amplification factor is 20, and as such it has good oscillator and radio-frequency amplifier characteristics, but rather poor modulator characteristics. The tube is illustrated in Fig. 24, in the position in which it should be operated, except that the plate should be mounted in a water jacket of suitable design. Since sole dependence of plate cooling is placed on the cooling water, it is imperative that a sufficient flow be maintained at all times when the tube is in operation. As with other similar tubes, there should be a positive interlock so that the filament and plate potentials cannot be applied unless there is a flow of water, and so as to disconnect these potentials in case the water flow fails. A steady flow of water of 3 gallons per minute per tube is necessary with this type of tube. The flow should be upwards through the jacket in order to remove any bubbles that may tend to form on the plate.

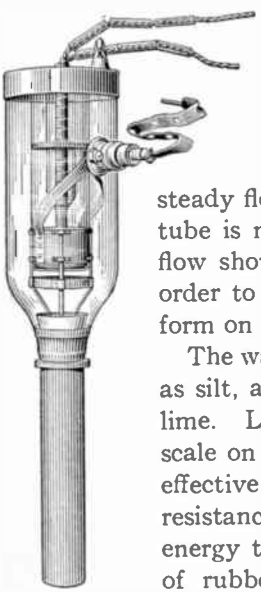


Fig. 24

The water should be free of any foreign matter as silt, and should not carry a large amount of lime. Lime and other impurities tend to form scale on the plate which makes the cooling less effective. Some impurities reduce the electrical resistance of the water, and thus cause a loss of energy to ground through this path. A length of rubber hose sufficient to provide a high-resistance path, usually about 15 feet, and coiled to provide a radio-frequency choke effect is commonly used as the inlet and outlet water connections.

97. The construction of the tube follows the general design of the three-electrode receiving tubes quite closely. The copper plate forms a part of the envelope, being joined to the glass portion by a metal-to-glass seal. The copper is finished by machining to a very thin edge, and by careful handling at the proper temperature the copper and glass are firmly sealed or welded together. The copper has nearly the same coefficient of expansion as has the glass used in this work, hence no excessive strains are produced on the seal.

The grid structure is supported from a special glass extension of the press so as to withstand the high voltages involved. The circulating radio-frequency grid current in high-frequency or short-wave operation is very large and hence the leads have a tendency to overheat. Special copper thimble grid seals and large grid leads, as illustrated in Fig. 24, tend to prevent overheating and consequent failure at this point. The filament current is likewise large and flexible copper leads are provided for direct connection with the filament supply circuit of the transmitter. Owing to the very low resistance of the filament when cold, special means must be employed to bring the filament up to operating temperature gradually.

98. The UV-848 radiotron is quite similar to the UV-207 in general features, the main difference being that the UV-848 has a low amplification factor, namely 8. The plate resistance is correspondingly reduced, giving characteristics that make this tube an excellent modulator. The low amplification factor is secured by special grid design, and the general appearance and operation features are quite the same as for the other water-cooled tubes.

A water-cooled tube of the same general type as those just mentioned, has also been made in a design with a relatively high amplification factor. The UV-863 radiotron, as it is called, has 50 for its average amplification constant. The plate resistance is also somewhat higher than in the other water-cooled tubes, but this is ordinarily not objectionable in the radio-frequency field to which this tube is chiefly applicable.

100-KILOWATT TUBE

99. The UV-862 radiotron has a nominal output rating of 100 kilowatts, which gives it special interest. In general appearance and design there is a considerable resemblance to the other water-cooled tubes. Naturally the size of all parts is much increased, and very special design, construction, and support features are necessary. The filament energy requires 207 amperes at 33 volts. The plate may operate with plate potentials up to about 20,000 volts. The amplification-factor and plate-resistance values are both rather high. The chief use of this tube is as an output tube in radio broadcast transmitters of rather high power. It is not well adapted for operation at frequencies higher than the usual broadcast range.

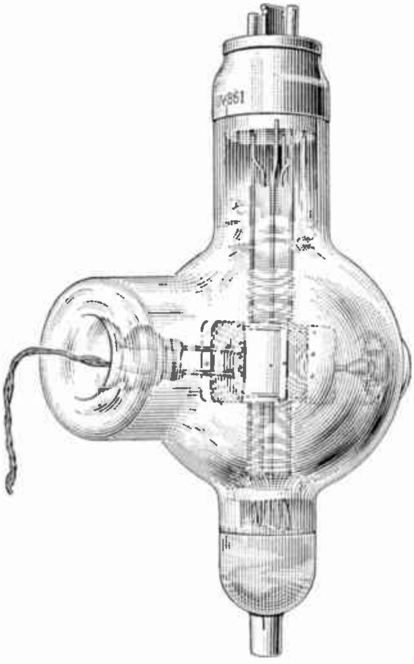


FIG. 25

FOUR-ELEMENT TUBES

100. UX-865. — The UX-865 is a four-electrode tube with a nominal output rating of 7.5 watts. Its chief advantages over the similarly rated three-electrode tubes is that this tube gives more stable and satisfactory operation in crystal-controlled oscillators, and in the subsequent radio-frequency amplifier stages of transmitters due to the reduced interelement feed-back. The plate lead, owing to the higher plate voltage, is brought out of the top of the bulb. The screen grid connects with the usual plate pin in the UX-type base.

101. UX-860.—The UX-860 radiotron is a still larger transmitting tube, and has a nominal output rating of 75 watts. The construction is quite special in that the control grid and plate leads come out of special arms to better enable the tube to operate at high frequencies or short wavelengths. These elements terminate in flexible external leads which connect directly with the input and output circuits. The screen grid connects with the usual grid pin in the standard UX base, in which the plate pin is not used.

102. UV-861.—A still larger tube of similar design is called radiotron UV-861. It has a nominal output rating of 500 watts which can be easily obtained at quite high frequencies or short wavelengths. The tube is illustrated in Fig. 25 in the recommended operating position, namely, with the filament end up. A special cap of low capacity is placed on the control-grid arm to permit mounting the tube between suitable mounting clips. The blade in the base on the filament end connects with the screen grid. The plate element terminates in a double flexible lead rather than a base so as to keep the stray capacity effects down to a minimum.

TRANSMITTING-TYPE RECTIFIER TUBES

103. The high-vacuum rectifier tubes are often made in designs closely paralleling the three-electrode transmitting and receiving tubes of the same general class. This permits of considerable uniformity in appearance and design. Such, for instance, is the case with several of the rectifier tubes of moderate and high-voltage rating which are quite similar to certain of the three-electrode transmitting tubes. In fact, many of the rectifier tubes that have been used in transmitting sets are practically identical with the corresponding three-electrode tubes with the sole exception that the grid structures are omitted.

The characteristics of many such commercial tubes are given in Table III. It will be noted that there are two water-cooled tubes in this table. Extreme care must be exercised in the operation of such tubes, as they will be instantly damaged if an attempt is made to operate them without such cooling. Even lighting the filament without a good flow of water on the plate may damage the tube beyond repair. Also, extra care in handling must be observed with these tubes, because of the delicate nature of the metal-to-glass seal.

TABLE III

TRANSMITTING-TYPE RECTIFIER DATA

Tube Type Number	Filament Data			Maximum Peak in Inverse Voltage	Maximum Peak Plate Amperes	Type of Cooling	Maximum Overall Dimensions	
	Type	Volts	Amperes				Length Inches	Diameter Inches
UV-217-A	Thoriated	10.0	3.25	*1,500	**.20	Air	$7\frac{7}{8}$	$2\frac{5}{16}$
UV-217-C	Thoriated	10.0	3.25	*3,000	**.15	Air	$8\frac{1}{2}$	$2\frac{5}{16}$
UV-866	Ox. Coated	2.5	5.00	5,000	.60	Air	$6\frac{5}{8}$	$2\frac{5}{16}$
UV-1651	Tungsten	11.0	14.75	*4,000	**.25	Air	$14\frac{3}{8}$	$4\frac{1}{16}$
UV-872	Ox. Coated	5.0	10.00	5,000	2.50	Air	$8\frac{1}{2}$	$2\frac{5}{16}$
UV-869	Ox. Coated	5.0	20.00	20,000	5.00	Air	$14\frac{3}{8}$	$5\frac{1}{16}$
UV-857	Ox. Coated	5.0	60.00	20,000	20.00	Air	$19\frac{7}{8}$	$7\frac{1}{8}$
UV-218	Tungsten	11.0	14.75	50,000	.75	Air	$15\frac{1}{2}$	$5\frac{1}{16}$
UV-856	Tungsten	11.0	16.25	50,000	.85	Air	$15\frac{1}{2}$	$5\frac{1}{16}$
UV-219	Tungsten	22.0	24.50	50,000	2.50	Air	$22\frac{5}{8}$	$6\frac{1}{8}$
UV-855	Tungsten	14.5	52.00	50,000	5.00	Water	$20\frac{1}{4}$	$4\frac{5}{32}$
UV-214	Tungsten	22.0	52.00	50,000	7.50	Water	$20\frac{1}{4}$	$4\frac{5}{32}$

*Max. A-C input (R. M. S. Value) volts.
**Max. D-C Load Amperes.

TELEVISION TUBES

PHOTO-ELECTRIC CELLS

FUNCTION OF PHOTO-ELECTRIC CELLS

104. Photo-electric or light sensitive tubes or cells are of great importance in the various phases of the transfer of visible intelligence by wire or radio channels. The cell must convert abrupt and gradual light changes into corresponding electric-current variations quite as a microphone converts sound variations into electric-current changes of a similar nature. The cell should produce these changes with fidelity and with no appreciable time delay.

CONSTRUCTION OF PHOTO-ELECTRIC CELLS

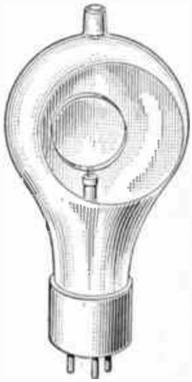


FIG. 26

105. The so-called photo-electric cell, one type of which is shown in Fig. 26, possesses a material that will emit electrons under the influence of light. The active surface is called the cathode as in other tubes, and the containing bulb is evacuated. Opposite to the active surface is a clear space or window through which the desired light may enter the bulb. Near the center of the tube is located the collecting electrode, or anode, which may take the form of a ring, as shown in the figure, or other convenient shape so designed as not to shield the active surface unnecessarily. The anode is carefully insulated from the active cathode, and with its positive potential attracts the emitted electrons and establishes an electric current between these two electrodes.

106. In a photo-electric cell the active material is usually one of the alkali metals, their hydride compounds, oxides or amalgams, all of which are very active both chemically and photo-electrically. Sodium, potassium, and cæsium are very satisfactory for this work, with potassium being used most extensively owing to its ease of handling. The compounds called hydrides are more light sensitive than the pure metals, hence are most commonly employed. The tubes are often made still more light sensitive by being filled with an inert gas such as helium, neon, or preferably argon, none of which elements will react with the active photo-electric material. The photo-electric current will be increased by the ionization produced as the electrons strike the added gas particles.

OPERATION OF PHOTO-ELECTRIC CELLS

107. The operating characteristic of the photo-electric cell is quite critical and it should be observed and adjusted carefully. In no event should the gas-filled type of tube be worked at the glow point, else short life may be expected. It is advisable to operate with a high resistance in series in the circuit so that the current may not become great enough to damage the tube. A milliammeter in series in this same circuit is very useful in indicating that the safe operating conditions are not being exceeded.

The photo-electric cells used in the pick-up of light variations are mounted so as to receive a maximum amount of light reflected from the subject or received from a screened lamp. The subject may be brightly illuminated and the light variations recorded through a suitable scanning disk, or the subject may be illuminated by a moving beam or point of light which is reflected to actuate the photo-electric cells grouped near-by. The photo-electric cell may be connected in a local battery circuit, and its output variations of current coupled with a conventional high-quality amplifier. The signal may then be broadcast over a suitable type of transmitter or carried over telephone lines.

108. On motion-picture films conversation and music accompanying the subject may be recorded beside the action picture. This record may be a path of variable density in the emulsion taken in a path of constant width. Or the record may be a path of variable width modulated in amplitude in accord with the variations of the desired voice and music. The path of variable density would carry this audible record as an audio-frequency change in density of the emulsion. These changes in the record are capable of varying the light from a beam focused on the film that reaches a suitable photo-electric cell. The changes in light reaching the cell vary its resistance and consequently the current, which is varied so as to reproduce the voice or music in perfect synchronism with the action of the pictures on the film.

TELEVISION RECEIVING TUBES

GENERAL CHARACTERISTICS

109. The tubes used in television reception comprise fundamentally two plates in a suitable gas. A Raytheon type called the Kino-lamp is illustrated in Fig. 27. The tube operates with a normal current of about 15 milliamperes at a potential of 220 volts. The two plate-like electrodes are rigidly mounted yet carefully insulated from each other. Only one electrode is visible in the illustration. The electrodes are rather large in area as one must furnish the picture background on which the image is observed. The direct potential applied to the plates causes a steady uniform glow to be produced on one plate. This is produced by ionization of the inert gas such as neon or argon with the glow appearing at the cathode or negative electrode. The signal variations produce corresponding changes in the intensity of the glow, or it may be completely extinguished and produced so that, with suitable auxiliaries including a scanning method, a reproduced image of the subject may be observed.

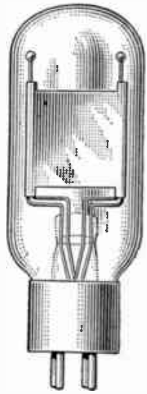


FIG. 27

OPERATION

110. In using television tubes for reception the operating conditions recommended by the manufacturer should be carefully followed if best results are desired. A milliammeter in the tube circuit will provide a check as to the actual current so that the rated value will not be exceeded. The scanning disk should, in general, rotate so that the holes move from right to left, or counterclockwise, at the receiver. Also, the holes should in most cases move inwardly or toward the center as successive ones pass the tube. If the picture is inverted the disk must be reversed on its shaft or the direction of rotation of the motor reversed.

111. The audio-frequency system must be particularly good for television reception in a satisfactory manner. Very careful tuning of the radio-frequency stages is an important prerequisite. Special design of the audio-frequency amplifier is essential because of the wide range of frequencies which must be amplified equally, or nearly so, else serious distortion will be encountered.

Detection by means of a biased detector tube, or so-called plate rectification, is to be preferred, as the quality is very good with this method. If the detector tube employs a grid leak and condenser, the sensitivity will be greater, but the fidelity will be reduced. In order to receive a positive image, with a black figure and colored background, the amplifier must have the proper number of stages. The number generally required is an odd number when the detector operates with a grid condenser and leak. This assumes that the transmitter is sending out positive images, which is usually the case. If the image is observed as a negative it may be corrected to a positive by adding or subtracting one audio-frequency stage.

112. If the detector stage operates as a plate rectifier with a high grid bias, the audio-frequency amplifier should usually have an even number of stages. If the image shows up as a negative it may be corrected to a positive by adding or subtracting one stage. Any suitable output tube may be used with the correct plate current for the television tube, and at a potential in excess of the rated starting voltage of the television tube.

UNDAMPED-WAVE RADIO COMMUNICATION

Serial 2018-2 Edition 1

SENDING TELEGRAPH SIGNALS

INTRODUCTION

DEFINITION OF TERMS

1. Instead of using damped radio-frequency wave-trains, another system of radio communication makes use of a series of high-frequency radio waves in which the amplitude of the waves remains practically constant throughout the series. By **undamped-wave radio communication** is meant the system in which the signal, if continued, would be an unbroken or undamped series of waves of alternating current. This is in contrast to damped-wave radio telegraphy in which the radiated energy is broken up into short wave-trains, each consisting of several cycles of high-frequency current. As the radio-frequency waves are continuous, during one element of a signal, the name *continuous-wave radio telegraphy* is often applied, and is frequently used interchangeably with that of undamped-wave radio communication. The waves in radio-telegraph practice may be interrupted at intervals into short and long groups to give the dots and dashes of the telegraph codes.

ADVANTAGES OF SYSTEM

2. The following are some of the advantages of the undamped-wave radio system: When damped-wave signals are used, all of the cycles of current are not of the same amplitude, and despite every effort, tuning cannot be accurate enough to include all of the waves to the best advantage. In case continuous waves of constant amplitude are used, the tuning at the receiving station may be made very sharp, and on one definite wave-length. In the damped-wave system, the antenna is energized for only a part of the time, while in the undamped system the power supply is continuous, a fact which causes a larger rate of energy radiation in the latter case.

USE OF DAMPED WAVES

3. In the early days of radio communication the various spark systems of damped-wave signaling provided practically the only satisfactory method of producing radio-frequency current oscillations; hence this system was in almost universal use. With the development of the art, and by the application of new principles, several devices have been produced which enable radio communication to be established by using continuous alternating currents of exceptionally high frequency. The use of damped waves at the present time, particularly in small power sets, is due largely to the fact that such transmitting apparatus may be constructed and operated very conveniently and cheaply, especially in these sizes.

HIGH-FREQUENCY ALTERNATORS

ALEXANDERSON ALTERNATORS

4. The *Alexanderson alternator* is an alternator of very high frequency, and the generated energy may be radiated direct from the antenna as produced. This type of alternator has been described in a previous Section. Considerable expense is attached to the installation of this set, partly on account of the large amount of auxiliary apparatus required. Great success has accompanied the use of this equipment, and it promises to become one of the most important and common machines in long-distance radio communication.

5. Alternator in Antenna Circuit.—As the Alexanderson alternator generates voltage waves at radio frequency, it may be connected directly in the antenna circuit, as indicated at *a* in Fig. 1. In the above case tuning to an exact wave-length is accomplished by varying the number of turns of the inductance coil *b* which are actually connected in the antenna circuit. A wide variation is not usually necessary or indeed desirable in the large power stations using this type of equipment, as they are ordinarily designed to operate on one particular wave-length. As the electrical characteristics of the apparatus at the sending station may vary, some slight change may be necessary from time to time to keep the station operating on the desired wave-length.

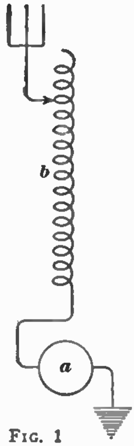


FIG. 1

6. Alternator Coupled to the Antenna.—Inductive coupling of the radio-frequency alternator *a* to the antenna, using an air core transformer, is shown in Fig. 2. This circuit arrangement is practically identical with the preceding one, but is preferable in many cases, as more accurate tuning of the radiating system may be secured by adjustment of the primary winding *b* and the secondary *c*. When it becomes desirable to decrease the radiated energy, the coupling between the coils *b* and *c* is decreased. Detailed connections are not shown in either case, as they vary considerably in the different stations in order to conform with local conditions.

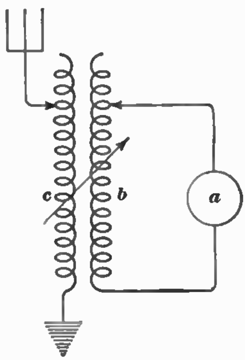


FIG. 2

7. Sending Key.—The key for interrupting the generated wave and producing thereby the required dots and dashes for telegraphic signaling, is preferably connected in the field circuit of the alternator. The small field current may easily be interrupted, and this, by deenergizing the magnetic circuit intermittently, causes dots and dashes of the code to be produced and ultimately radiated. By using special sending and receiving devices, operation with the Alexanderson alternator has been successfully carried on at speeds up to 200 words per minute.

8. **Constant-Speed Motor.**—As the wave-length changes to some extent with variation in the frequency, it is important that the alternator's speed be kept constant. In most of the installations the alternator is driven by an electric motor so arranged and controlled as to give a very uniform speed, even when the sending key is being operated. Positive drive is assured through a high-ratio gear connected between the machines so as to run the alternator at a speed several times greater than that of the motor. By this means the speed of the motor may be kept fairly low, and a machine of special design to withstand the terrific speed of the alternator is not required.

OTHER TYPES

9. Other types of alternators with auxiliary apparatus and circuits ingeniously applied have been used in radio communication, but have met with only limited adoption. The circuit arrangements are, in general, very complicated. It is highly probable that with further development some of these machines may be more commonly used, and become active competitors of the alternator just mentioned.

ARC SETS

GENERAL PRINCIPLES

10. The *arc* system for generating high-frequency undamped waves has been used in many stations, with considerable success. This is frequently called the *Poulsen arc*, as it was invented by Valdemar Poulsen. Many refinements have

been added since its original introduction. This device is especially applicable to medium and high-power work, in which fields it finds its greatest usefulness.

DIRECT-CURRENT ARC

11. The fundamental part of an arc set is the electric arc which is instrumental in producing the high-frequency oscillations. When an electron is taken from or added to a neutral atom or molecule, the charged particle thus formed is called an *ion*. This process is known as *ionization*. The particle will have a negative charge if one or more electrons are added to the formerly neutral body, and a positive charge if one or more electrons are removed.

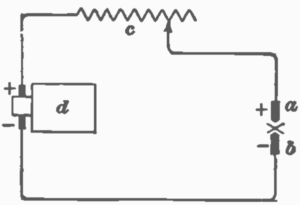


FIG. 3

Ionization may be set up by heat vibration as well as by other means. When the two conducting electrodes *a* and *b*, Fig. 3, are brought together, a current is established, the surface contact heated, and ionization of the air between the electrodes produced. The liberated ions act as carriers of electricity and a current can pass from one electrode to the other even when these are separated a short distance. The high temperature of the arc produces incandescence of the particles of matter in and near the ends of the electrodes and thus a glow of light. The flow of ions produces a current-carrying path of rather low resistance between the electrodes. A large current is prevented by the introduction of the variable resistance *c* between the direct-current generator *d* and the arc.

THE OSCILLATING ARC

12. An arrangement of apparatus that will establish an oscillating arc was developed by Poulsen and consists essentially of a direct-current arc shunted by a tuned oscillating circuit. When the electrodes forming the terminals of the arc are connected to a source of direct current, a high-frequency alternating current will be established in the oscillating circuit. Fig. 4 shows the fundamental connections of the arc and its shunt circuit. The electrodes, usually of copper and carbon, are shown at *a* and *b*; a variable resistance at *c* and an inductance coil at *d*, both in the generator circuit; an electromagnet in two sections at *e*; a variable condenser at *f*; a variable inductance coil at *g*; and a direct-current generator at *h*. The oscillating circuit consists of the condenser *f* and the inductance coil *g* and forms a shunt across the terminals of the arc.

When a direct current passes between the electrodes, thus forming an arc, a voltmeter connected across the electrodes will indicate a certain voltage. If, with fixed electrodes, the current through the arc is increased, greater ionization of the

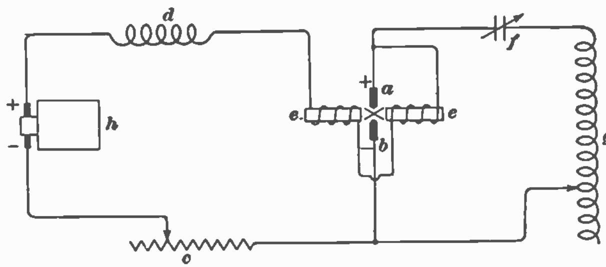


FIG. 4

air is produced, the cross-sectional area of the arc is increased, and the resistance offered to the passage of current reduced to such an extent that the voltage across the electrodes is reduced. If the current through the arc is reduced, the voltage across the electrodes is increased. An inductance coil in a circuit in which the voltage is variable tends to delay changes in the current beyond what would occur with the inductance coil omitted. Both of these effects are important when considering the operation of the oscillating arc.

The arc electrodes are first connected to the generator with the oscillatory circuit disconnected. The electrodes are placed in contact and then separated, thus starting the arc. The oscillatory circuit is then connected to the electrodes. As soon as this circuit is completed, the condenser begins to accumulate a charge; the left plate being positive since it is connected through coils *e* and *d* to the positive brush of the generator. Since the oscillatory circuit is in shunt with the arc, and the inductance coil *d* in the generator circuit tends to keep the generator current constant, the oscillatory circuit now takes from the arc some of the current that formerly passed through it. The current through the arc decreases, the voltage across the electrodes increases, and this increase in voltage aids in giving the condenser a higher charge than it would otherwise take.

The inductive coil *g* causes the highest point of the charging current in the condenser to take place a short time after the voltage across the electrodes has risen to its maximum value. When the condenser is fully charged no current passes through the oscillatory circuit and the arc carries the normal full current of the generator. The arc voltage resumes its previous value and for a very short interval of time does not vary.

13. Because of the effects just mentioned, the voltage of the condenser rises temporarily to such a value that it is higher than the voltage of the supply circuit. The condenser, therefore, starts to discharge a current through the arc from *a* to *b*, the current established by the condenser being in the opposite direction from that of the charging current. The discharge current through the arc is, therefore, in the same direction as that supplied by the direct-current generator. The current through the arc is increased, the voltage across the electrodes is decreased, and this decrease helps the condenser in sending current through the arc.

The inductance coil *g* in the oscillatory circuit causes the current in the condenser to be prolonged over what it would be if this coil were omitted. The discharge current will, therefore, continue past the point at which it would cease if the circuit had no inductance. As a result, the condenser accumulates a charge opposite in polarity to its former charge; the right-hand plate of the condenser *f* now becomes positive. As the charge of the condenser with its new polarity nears its end, the accompanying current through the arc and the oscillatory circuit dies out, and with normal conditions restored in the arc, the voltage of the arc rises and resumes its usual value.

The voltage of the condenser under the new conditions discharges a current from *b* to *a*. This discharge current neutralizes part or all of the generator current in the arc; thus raising the voltage across the electrodes. When the oscillating arc is properly tuned, the arc may be temporarily extinguished and the voltage from the generator sends a charging current into the condenser *f* in such direction as to make the left-hand plate positive again. This cycle of charges and discharges takes place continuously and an alternating current of high frequency is, therefore, established in the oscillating circuit.

FACTORS AFFECTING THE FREQUENCY

14. If the discharge current from the condenser is of such value that it is equal to or greater than the arc current, it will stop the current through the arc when the condenser current is equal to and opposes the generator current. When this condition is reached, the whole device is operating properly, and will continue indefinitely to do so. As this operation is dependent upon the values of inductance and capacity in the oscillating circuit, variable condensers and variable inductance coils are commonly installed, so that the circuit may be readily tuned. As soon as the arc is stopped, the supply voltage alone charges the condenser. The charge continues until the condenser has voltage sufficient to break down the arc gap and reestablish the arc. This cycle of events recurs at very frequent intervals and the time during which there is no current through the arc is actually very minute.

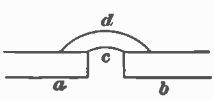


FIG. 5

Fig. 5 represents the two electrodes of the arc at *a* and *b*. The arc may be considered as established along some path between the electrodes, as at *c*, not considering the action of the electromagnets *e*, Fig. 4. When these magnets are energized by current from the generator, the stream of ions is forced to some position as at *d*, Fig. 5. The length of the arc is very much increased, and hence the magnets can stop, or blow out, the arc quite readily when the current in the oscillating circuit nearly if not entirely neutralizes the normal direct current in the arc. It is very important, in order to obtain a uniformly steady wave, that the arc be broken each time before there is enough voltage to start another one, or at least that the current in the arc be reduced an amount sufficient to cause the oscillating action to be continuous.

15. The operation of the arc, when establishing a radio-frequency current, is largely dependent upon the deionization of the space between the electrodes at an exceedingly rapid rate as soon as the current through the arc dies out. Several methods may be employed to deionize this space, and, when properly applied, the arc will oscillate steadily at a rate of several thousand oscillations per second. The tuning of the oscillating circuit by means of the variable condenser and variable inductance coil is an important factor in determining the frequency of the oscillations.

The flow of ions is affected by a magnetic field. A magnetic flux at right angles to the path of the current in the arc acts to distort the path of the flow of ions. This helps to break the arc and also prevents for the required time the reestablishment of another arc. If the ions were allowed to remain in the space around and between the electrodes, the voltage of the supply circuit might be able to establish another arc before the condenser had stored up a sufficient charge.

16. The chamber surrounding the electrodes is entirely enclosed. Hydrogen gas has been found to assist materially in dispersing the ions of the arc; therefore, a gas containing hydrogen is placed in the chamber. Illuminating gas is often used for this purpose, but as considerable foreign matter is also introduced, the chamber may require frequent cleaning to remove the soot accumulation. Another method which has met with considerable success is the introduction of some substance that contains a large amount of hydrogen. Either kerosene, alcohol, or ether is a suitable material, and the hydrogen is liberated by the intense heat of the arc. Provisions are usually made for introducing a small amount of liquid into the chamber continuously. Only a very few drops are required from time to time to supply the chamber with a sufficient amount of hydrogen gas.

The positive electrode, also called the anode, is made of copper, and is hollow. Water running through the interior of this electrode keeps it comparatively cool, and prevents it from being rapidly burned up by the intense heat of the arc. The negative electrode, or cathode, is of carbon and its supporting sleeve is frequently water-cooled to keep the temperature down. The cooling of the electrodes helps to disperse the ions and thus to quench the arc. In some cases the electrodes are placed in horizontal positions.

In order that the carbon electrode may be worn away uniformly, a small electric motor geared down to obtain a relatively low speed may be used for rotating the carbon electrode. The gap between the two electrodes may be adjusted by an extension handle, the latter being placed in such a position that it is within easy reach of the operator. In large apparatus the arc chamber is usually water-cooled to remove much of the heat generated by the arc.

17. The electromagnet windings being mounted on iron cores, act as impedance, or choke, coils. Such coils do not offer any opposition to direct current other than that furnished by the resistance of the wire. Their opposition to current at radio-frequency is strong enough to prevent the passage of such a current, and the high-frequency oscillating current established by the arc in the tuned circuit is effectually prevented from passing through the direct-current generator.

The strength of the magnetic field is usually made variable by switches which short-circuit some of the turns. The turns which are short-circuited do not receive any current and, therefore, do not establish a magnetic flux. When the frequency is high, the magnets should be strong in order to remove very rapidly the ions from the vicinity of the electrodes. With a lower frequency there is more time between the successive arcs. and the field strength of the magnets need not be so great.

ARC OSCILLATING CIRCUIT COUPLED TO THE SENDING ANTENNA

18. A method much used in high-power arc stations is shown in Fig. 6, in which the arc oscillating circuit is coupled to the antenna circuit. The high-frequency generating circuit is not unlike the ones which have been described. By means of an air-core transformer, the radio-frequency currents are transferred to the antenna circuit. The capacity of the latter circuit is furnished by the condenser effect of the antenna and ground. The inductance *a* is made variable, so this circuit may be tuned to the wave-length of the oscillating circuit. Where large currents are radiated it is desirable to produce dots and dashes by some means other than actually interrupting the circuit. Key *b* is connected around a few turns of the secondary of the transformer, and short-circuits them when in its

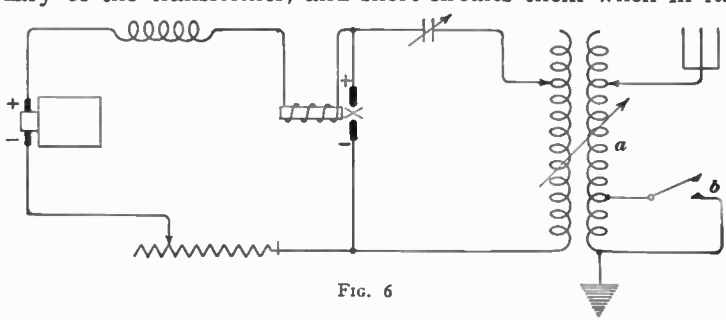


FIG. 6

closed position. The antenna circuit is then tuned to radiate at the desired wave-length, with the key down. When it is open, the aerial circuit is out of tune with the primary winding, and only a portion of the generated energy is transferred to the antenna circuit. What energy is radiated, is at a different wave-length than the one on which communication is established, and does not bother the receiving station. This extra wave is, however, apt to cause interference to other stations which may happen to be operating on wave-lengths near the value of this secondary wave. This system of producing signals is sometimes called the *detuning method*, and is often used in large power stations in which the high-frequency current is established by means other than arc sets.

ARC CONNECTED IN ANTENNA CIRCUIT

19. A method of connecting an arc-set to an antenna where only relatively low power is used, is represented in Fig. 7. The arc is connected directly in the antenna circuit, and the radio-frequency oscillations are established directly therein. As in the preceding case, the capacity in the oscillating circuit is due to the condenser action between the aerial and the ground. The inductance *a* is variable and the length of the radiated wave is determined largely by its setting. The key *b* is connected directly in the ground circuit, which is complete only when the key is down. In order that the arc may operate

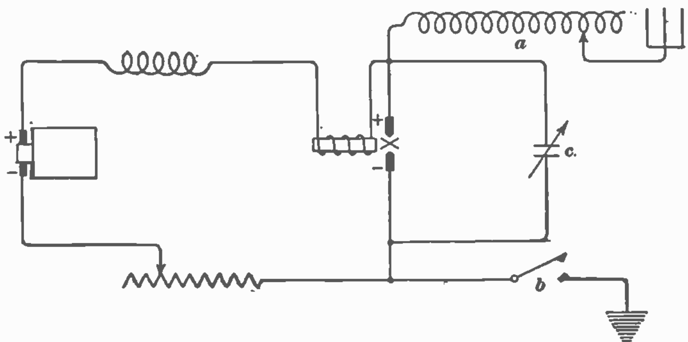


FIG. 7

continuously, it is shunted by a condenser *c*, which serves to maintain the high-frequency oscillations. This condenser helps to boost the strength of the signals when the arc is under normal operation.

Although the arc is operating all the time, energy is radiated only when the key *b* is closed. The key could be connected so as to short-circuit some of the turns of the inductance instead of opening the ground connection. Tuning should then be made so that the correct wave-length would be radiated with the key closed. Nearly full power would be radiated with the key either open or closed, and the arc would be in continuous operation. Under this condition no shunt condenser *c* would be required.

ELECTRON TUBES

GENERAL CONSIDERATIONS

20. Electron tubes are used in the production of continuous, or undamped, currents at radio frequency. The tubes are particularly useful in the transmission circuits of low-power stations rather than in similar circuits of high-power stations. The same type of tube may be used in either transmitting or receiving circuits, but special tubes have been developed for transmitting circuits that operate at higher efficiencies than the tubes of more general application. The principles underlying the operation of electron tubes when used as generators of oscillating currents were treated in a previous Section.

ELEMENTARY CIRCUIT ARRANGEMENTS

21. In Fig. 8 coil *a* is in the plate circuit, the inductance coil *b* is in the antenna circuit, and coil *c* is in the grid circuit. If the coils *a* and *c* of the elementary oscillating electron-tube circuit are coupled to the antenna coil *b* in the manner indicated, a radio-frequency current will be established in the antenna circuit. A small oscillation produced in the grid circuit will produce a greater change of current in the plate circuit, including the coil *a*. This coil being coupled to the inductance coil *b* produces oscillations in the coil *b* which react upon coil *c* in the grid circuit. The feed-back then serves further to amplify or increase

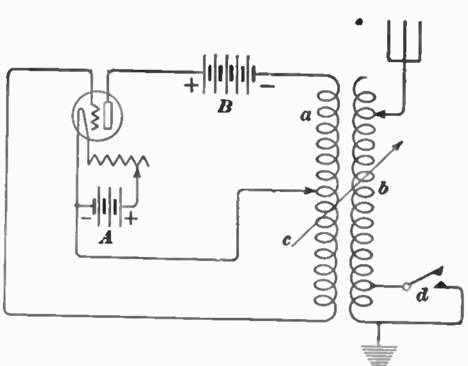


FIG. 8

the oscillations in the antenna circuit and to maintain them when once started.

As only the antenna circuit is a tuned circuit, and oscillating at the desired radio frequency, the radiated wave is very sharp. The frequency of the alternating current finally established depends primarily upon the tuning of the antenna circuit, although it is important that the coupling between the antenna coil *b* and the other coils *a* and *c* should be adjusted for the desired amount of energy transfer.

A key located as at *d*, may be used to send telegraphic code signals. The antenna is tuned to radiate signals of the desired wave-length with the key closed. Opening the sending key introduces a few additional turns into the antenna circuit, and energy is radiated but on a different wave-length. Operation seems to be best with this arrangement, although some interference is produced by the useless radiated energy. The key may be so located as to interrupt the antenna current, by opening the circuit, in which case good results may be expected. Placing the key in some part of the tube circuits is not satisfactory, as the action is sluggish and the radiated wave is apt to be ragged.

This system of producing radio signals is usually employed in low-power sets, as there is a definite limit to the amount of energy which may be transferred through the ordinary tube. Several tubes, however, may be connected to operate in parallel where large power output is desired, but the excessive cost of this expedient is generally prohibitive. Large capacity tubes have been developed for use in high-power stations.

COUPLED OSCILLATING CIRCUIT

22. A somewhat different circuit arrangement using an electron tube as an oscillator to produce undamped waves is indicated in Fig. 9. A fundamental requirement for the successful operation of this circuit is that the coupling between coils *a* and *b* must be quite close, that is, the coils must be brought close together, so that a large amount of the energy in the plate circuit is fed back to the grid circuit. When the varying electromotive force obtained from coil *b* is more than

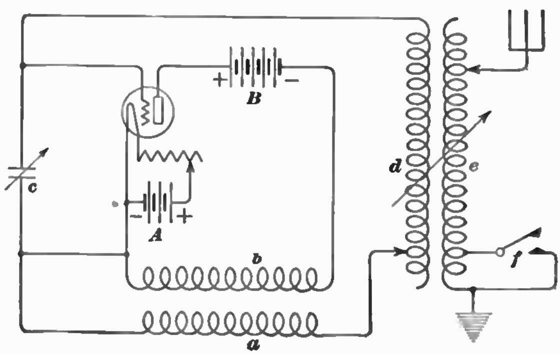


FIG. 9

enough to sustain oscillations in the oscillating circuit *a*, *c*, *d*, this circuit may be used as a source of sustained waves.

23. As the principle of operation of the oscillating circuit is somewhat different from the one just described, it will be explained briefly. The instant all the circuits are closed, starting with no voltage on the grid, there will be a current in the plate circuit which starts at zero and increases. The current through coil *b* induces an electromotive force in coil *a* such that one of its terminals is positive, and the other terminal is negative. The positive terminal being connected to the grid places a positive voltage on the grid which causes the current in the plate circuit to increase at a still faster rate. This increasing action is cumulative, and would continue indefinitely were there not some factors to limit it. In this case a limit is reached when the quantity of negative charges, or electrons, flowing in the tube from filament to plate becomes so great that a larger number cannot flow. This is the phenomenon described as *saturation* of the tube.

As the limiting point is approached, the increase in the current in the plate circuit becomes less rapid, a condition which causes the voltage at the terminals of coil *a* to decrease and a smaller electromotive force will be applied to the grid. A point is then reached where there is no further increase in the current in the plate circuit. At this instant, with a steady current through coil *b*, there will be no voltage induced in coil *a* and consequently none applied to the grid. The current in the plate circuit then decreases in order to come down to its normal value for zero grid voltage.

With a decreasing current through coil *b*, there will be an electromotive force induced in coil *a*, which is in a direction opposite to that induced when the current in coil *b* was increasing, that is, the terminal which was positive is now negative and the other terminal is positive. The negative voltage applied to the grid causes the current in the plate circuit to be decreased at an increasingly faster rate, this in turn causing a still greater negative voltage to be applied to the grid. This decreasing action tends to continue indefinitely, but a limit is reached when the plate current reaches zero. Therefore, as the limiting point is approached, the decrease in the current in the plate circuit becomes less rapid, which causes the voltage induced in coil *a* to decrease, and a smaller electromotive force to be applied to the grid. A point is then reached when there is no further decrease in the current in the plate circuit, the grid then being at zero voltage. The current then increases in order to reach its normal value at zero grid voltage.

24. A complete cycle of changes of current in the oscillating circuit has been completed and the action continues during the operation of the tube. Thus, there is a voltage at the terminals of coil *a* which is continuously oscillating between positive and negative values. The coil *a* is included in the circuit *a*, *c*, *d*; therefore, there is an oscillating current set up in this circuit whose frequency depends upon the amount of inductance and capacity in the circuit; that is, the frequency depends upon the inductance and capacity properties of *a*, *c*, and *d*.

All that is necessary to use this arrangement for transmitting sustained wave signals is to couple coil *d* to a coil *e* forming part of an antenna circuit. A transmitting key could be located as shown at *f* to interrupt the signals sent out on the desired wave-length, into intelligible dots and dashes of the telegraphic code.

GENERATOR IN PLATE CIRCUIT

25. Another complete circuit arrangement for transmitting undamped waves by means of an electron tube is indicated in Fig. 10. As in other cases, the plate circuit is coupled to the grid circuit through coils *a* and *b*, and supplies the latter with

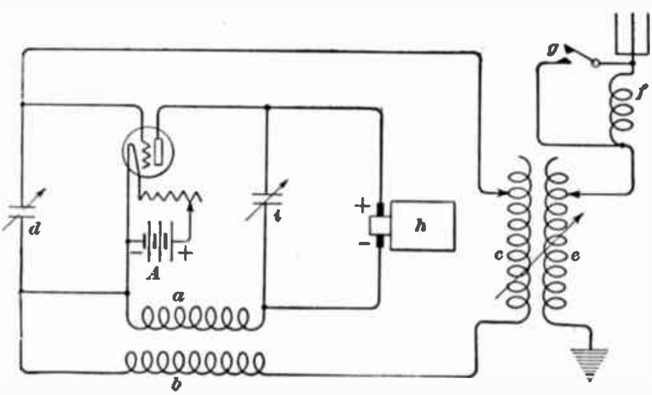


FIG. 10

energy. The oscillating circuit consisting of *b*, *c*, and *d*, is coupled to the antenna coil *e*, producing undamped oscillations therein. The coil *f*, which is short-circuited by a sending key *g*, is represented as being separate from coil *e*, although this is not always the case, it being feasible to have the sending key short-circuit a few turns of any coil in the antenna circuit.

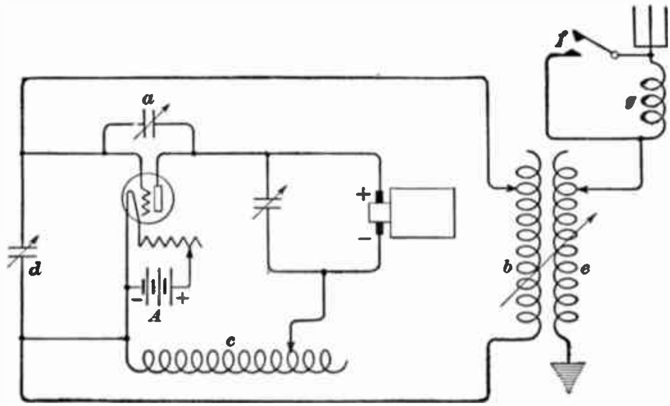


Fig. 11

26. A small direct-current generator *h* is used in place of a *B* battery, for the reason that a much higher voltage is necessary in the plate circuit of an electron tube used for transmitting than is required in the plate circuit of one used for receiving. A generator is usually a better device than a battery to provide a high electromotive force. The condenser *i*, shown connected in parallel with the generator, is for the purpose of providing a good path around the generator for the rapidly pulsating current in the plate circuit, as the generator windings offer high opposition to the pulsating current. The production of a greater amount of power may be secured by connecting two or more tubes in parallel;

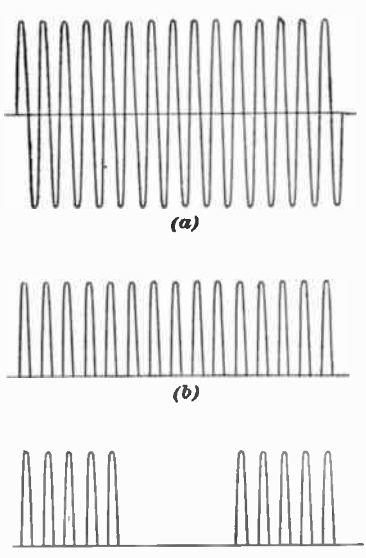


Fig. 12

that is, all the grid terminals would be connected to a common terminal, and all the plate terminals, to a common terminal, and then these common points would be connected in the circuit just as if they were the terminals of a single tube. The filament terminals are also connected in parallel with a separate control resistance in each filament circuit, so that the filament current of each tube may be accurately adjusted to its best operating value. This will help compensate for any differences in the operating characteristics of the tubes. It has not been found satisfactory to connect the filaments of tubes in series, especially power tubes, as the plate current of some of the tubes may cause a larger current in the filament circuit of some tubes. This would be due to the combination of the plate current with the filament current, which, in power tubes is fairly large when compared with the filament current.

27. Another distinctive type of connection is indicated in Fig. 11. Here the plate circuit is coupled to the grid circuit by means of a condenser *a* instead of by inductance coils. The condenser acts, as did the coils of previous cases, to transfer some of the plate-circuit energy back to the grid circuit. The frequency of the oscillations depends on the values of the inductances *b* and *c*, and capacities *a* and *d*. As before, energy is transferred to the antenna by means of inductance coils *b* and *e* which are coupled together. A key *f* is shown arranged to short-circuit a small coil *g* consisting of a number of turns connected in the antenna circuit.

RECEIVING TELEGRAPH SIGNALS

FUNDAMENTAL PRINCIPLES

28. In order to be effective in radio communications, the radiated waves should have a frequency above 20,000 cycles. Undamped waves are a continuous series of these high-frequency waves, as shown by view (*a*) in Fig. 12. If undamped waves at this frequency were sent through a telephone receiver, they would not produce a sound, as the mechanical features of the receiver would prevent its response, or vibration of the diaphragm, at this tremendous rate. The circuit arrangement entirely suitable to the reception of damped waves will not be affected by undamped-wave, radio-telegraph signals, and other circuits and devices must be employed, or, in some cases, merely combined with the damped-wave receiving set.

CIRCUIT INTERRUPTING DEVICES

BUZZER

29. One method of receiving and detecting sustained waves is indicated in Fig. 13. Here the arrangement of circuits is exactly the same as for receiving damped-wave signals, except that a circuit-interrupting device *a* has been inserted in series with the detector *b* and telephone receivers *c*. The interrupter forms part of an electric buzzer *d*, whose operating circuit is also shown connected to its own local battery *e*. The buzzer operates at its normal audio frequency, and the vibrating armature periodically opens and closes the circuit through the detector *b* and telephone receivers *c*.

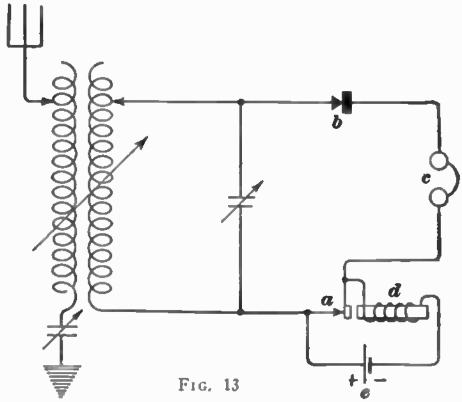


Fig. 13

The action of breaking the circuit cuts up the received radio-frequency waves into groups of a few high-frequency oscillations, with quiet intervals separating the periods during which current is passing in the circuit. As has been explained, a detector rectifies any alternating-current wave passing through it, and would in this case pass a pulsating current through its circuit similar to that represented in view (*b*), Fig. 12, were it not for the buzzer. As the circuit is opened at intervals by the buzzer, the rectified pulsations of current that remain will be grouped somewhat after the manner shown in view (*c*). These grouped current pulsations passing through the coils of the telephone receivers will act upon their diaphragms, for, although the individual pulsations are at a high frequency, they are all in one direction, and thus their combined action is to hold the diaphragms in their active positions during each group of pulsations. The diaphragms will resume their normal positions during the intervals between wave-trains. These groups of pulsations occurring at audio frequency give audible signals, a long series of groups representing a dash, and a short series of groups representing a dot in the telegraphic code.

CHOPPER

30. Undamped waves may be received by connecting a *chopper* in the detector and receiver circuit of a damped-wave

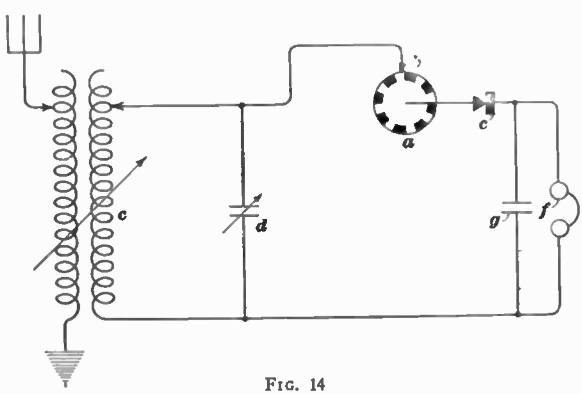


Fig. 14

receiving set. This will result in the circuit arrangement indicated in Fig. 14. The chopper normally consists of a toothed wheel *a*, and a brush or contact point *b* which touches the teeth momentarily as they pass. A motor rotates the toothed wheel at a fair rate of speed, and the teeth make brief periodical contact with the brush *b*. During the period of contact, the oscillating circuit, consisting of the inductance *c* and the condenser *d*, is connected to the circuit through the detector *e* and the telephone receivers *f* just as in a damped-wave set. As was the case there, a small condenser shunting the telephone receivers, as at *g*, may be used to smooth out and assist in receiving the high-frequency pulsations.

Here as in other continuous-wave systems, the oscillating circuit receives undamped radio-frequency signals. As long as the teeth of *a* do not touch the brush *b* the receiver circuit is open and no signal is heard. When the contact points close the receiver and detector circuit a few cycles of radio-frequency current are allowed to pass from the oscillating circuit. However, the detector performs its rectifying action and allows only a pulsating current to pass through the telephone receivers. These few pulsations of current, which pass during the contact period, produce one click in the telephone receivers. The frequency of the opening and closure of the detector and receiver circuit, and, consequently, the tone of the received signal may be controlled to a large extent by regulating the speed of the chopper wheel. The note produced by the telephone receivers is not quite as uniform nor as easy to receive as in some other receiving systems.

TIKKER

31. The *tikker* depends upon a make-and-break contact to produce audible signals from undamped waves. In one form it uses the circuit of Fig. 15, which is quite similar to that of Fig. 14. A grooved wheel *a*, Fig. 15, forms one side of the contact and is rotated by a motor. A spring *b* presses into the groove of wheel *a* and makes a sliding and imperfect contact. The minute irregularities in the wheel open and close the contact very frequently, producing a series of breaks between the oscillating circuit and the detector and receiver circuit very similar to that of the chopper. A small condenser *c* shunting the telephone receivers *d* will help in the reception of the high-frequency impulses.

In the reception of high-frequency signals corresponding to the shorter wave-lengths, it seems desirable to use the detector indicated at *e*. On the lower frequencies, it is quite feasible to eliminate the detector, but a much larger condenser must be used at *c*. The rotation of the wheel *a* must also be increased, and this increase will cause a more frequent closure and opening of its circuit. The inductance *f* and condenser *g* store up considerable energy while the receiver and condenser circuit is open at the tikker. This energy is instantly trans-

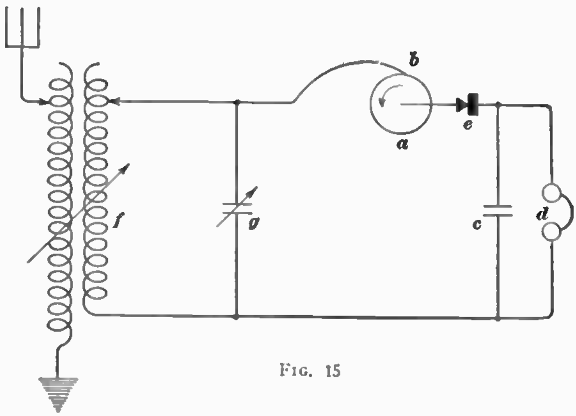


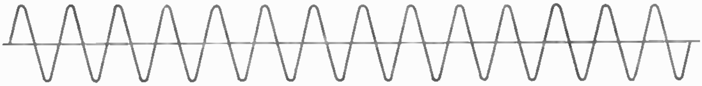
FIG. 15

ferred in bulk to the large condenser *c* while the tikker contact is closed. This contact opens in time to prevent condenser *c* from discharging back through the oscillating circuit, and the charge is therefore expended in producing a click in the telephone receivers. The irregular contact of the tikker and the consequent non-uniform charges on condenser *c*, produces a tone neither uniform nor musical. More pronounced makes and breaks are obtained by rotating the wheel against the contact point, as shown by the arrow in the figure.

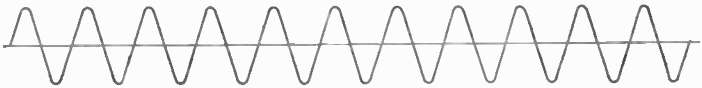
BEAT CURRENTS

PRINCIPLE OF OPERATION

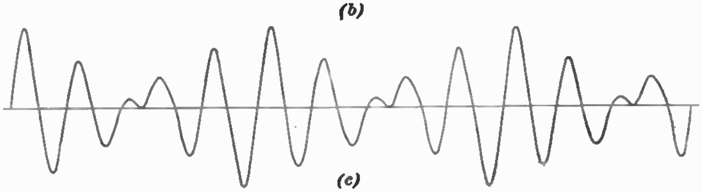
32. Two undamped-current waves of different frequencies are indicated in Fig. 16 (*a*) and (*b*). When these two waves are combined into one wave by adding the instantaneous values of the two separate waves, taking into consideration their positive and negative relations, the resulting wave will be similar in form to that shown in view (*c*). This wave is an



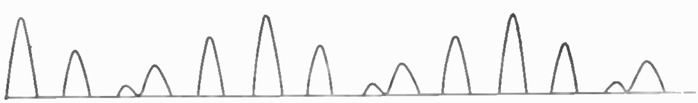
(*a*)



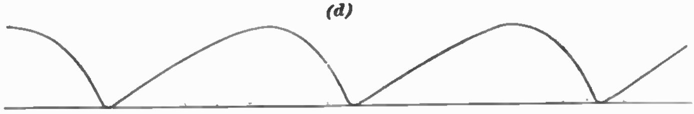
(*b*)



(*c*)



(*d*)



(*e*)

FIG. 16

indication of what is known as a *beat current*. The amplitudes of the individual alternations of the beat current are not uniform. Periodical increases and decreases of amplitude are formed by the addition of the two separate waves. Maximum points are due to the addition of two simultaneous maximum values in the same direction, and minimum points are due to two simultaneous zero values or to the addition of two simultaneous maximum values, one of which is positive and the other negative. The amplitudes of the waves between the maximum and the minimum points depend upon the simultaneous individual values and their positive or negative relations.

The time between any two maximum points on the beat-current wave is much longer than the time occupied by one cycle of either of the two separate waves. The beat current when rectified, view (*d*), and further modified by the action of the telephone receivers and their condenser produces a periodic current of audio frequency, view (*e*).

HETERODYNE RECEPTION

33. Alternating-Current Generator.—The *heterodyne* method of receiving depends on the principle of superimposing upon the incoming undamped high-frequency wave a similar wave of a slightly different frequency. Fig. 17 shows

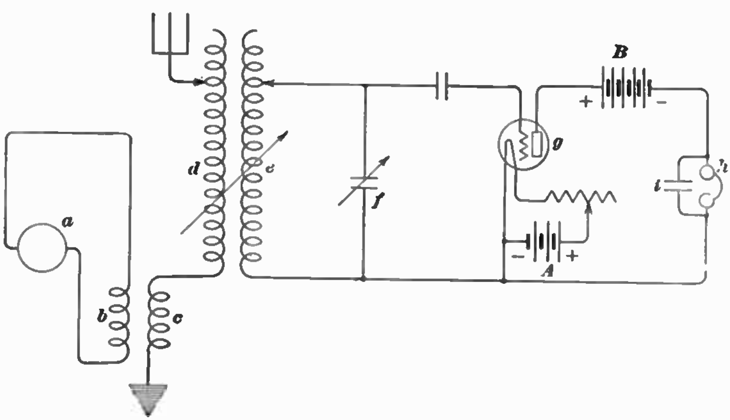


Fig. 17

one arrangement of circuits for heterodyne reception. A small alternating-current generator is shown at *a*. The primary coil *b* and the secondary coil *c* of a transformer serve to couple the generator and antenna circuits.

Suppose the incoming high-frequency current to be that represented by Fig. 16 (*a*) and the alternating current of another frequency supplied to the antenna circuit by the generator to be that shown in view (*b*), then the combined current, or beat current, in the antenna circuit may be indicated by view (*c*). The beat current in coil *d*, Fig. 17, produces a current of similar wave shape in the oscillating circuit consisting of the secondary coil *e* and the condenser *f*. The electron tube *g* rectifies the beat current, Fig. 16 (*c*), into the form shown in view (*d*). The current represented by view (*d*) is seen to be made up of high-frequency pulsations of current, but divided into beats or groups by their large and small amplitudes. This rectified current in the plate circuit of tube *g*, Fig. 17, operates the telephone receivers *h*, and also charges the shunt condenser *i* during the time of each short series of high-frequency current pulsations, or with each beat. The shunt condenser helps to smooth out the rapid pulsations impressed on the telephone receivers, causing the current to assume the general form shown in Fig. 16 (*e*), and this current produces a click in the receivers for each pulsation of the beat current. The diaphragms of the telephone receivers will not act quickly enough to respond to the individual radio-frequency pulsations, but will produce audible sounds when a current represented by the audio-frequency wave, view (*e*), passes through the coils of the telephone receivers.

34. The beat frequency depends directly upon the difference between the frequencies of the component waves; that is, if there is very little difference between the received and applied frequencies, the beat frequency will be low, while, if there is a large difference, the beat frequency will be high. The frequency of the received wave is, therefore, fixed for any given conditions, but by varying the frequency of the local applied current, the beat frequency may readily be controlled. In this manner sharp tuning is possible, and many interfering stations may be easily tuned out. It should be noted that a crystal detector or some other form of rectifier might be used in place of the electron tube; the action of the tube in this arrangement being simply to rectify the beat current caused by the interference of the two high-frequency oscillations.

To supply this current, the alternator for generating the local oscillations might just as well be connected to the local oscillating circuit, through coil *c*, Fig. 17, as to the antenna circuit. The principle of operation would remain the same as previously described. This method of receiving signals tends to amplify the signals or make them stronger, as the local energy is added to the incoming signals to produce the effective beat current. The coupling between coils *b* and *c* should be of such value as to induce a current in the antenna about equal to that received from the sending station.

The beat and consequent audio frequency current pulsations of Fig. 16, will be received only while both of the component high-frequency currents are established. The antenna, Fig. 17, will receive its high-frequency current from the sending station only while that station is sending out the dot-and-dash signals. During the intervals or spaces between these elements of the signals there will be only the locally generated high-frequency current in the receiving set. This radio-frequency current is, however, unable to produce any audible signals of itself and is used up in the receiving set as waste energy. It is also important that the local oscillating current be established before the incoming signals can be received.

35. Electron-Tube Generator.—The heterodyne method of receiving undamped radio signals may be used with an electron tube acting as a generator. Fig. 18 shows such an arrangement in which tube *a* and its associated circuits act as the generator of a radio-frequency current. Through the action of the transformer coils *b* and *c*, this current is transferred to the antenna circuit where it is combined with the current of the incoming wave to form a beat current. The receiving circuit including the electron tube *d* is of the type commonly employed for damped waves. The signals reaching the tube *d* are carried by the beat current. The tube rectifies the beat current and the rectified current operates the telephone receivers *e*.

AUTODYNE RECEPTION

36. Instead of using two tubes as in the preceding case, one electron tube may be used to perform the complete operation of receiving and detecting the incoming undamped radio-frequency oscillations. This is known as the *autodyne* method, which, briefly stated, is the system of using one tube to func-

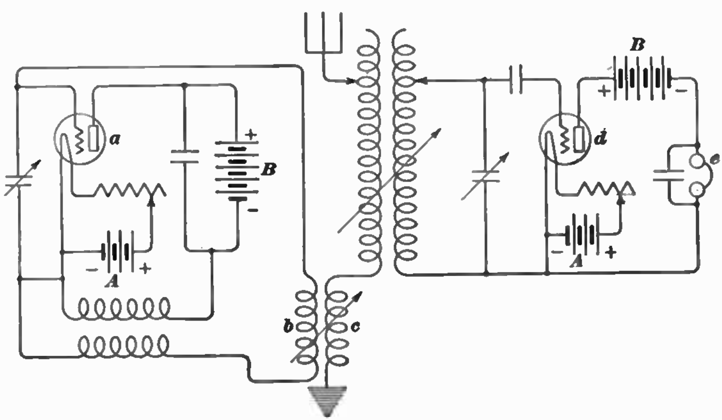


FIG. 18

tion as a generator of high-frequency current oscillations as well as to function as a rectifier for the beat current.

Fig. 19 shows a circuit diagram based on the autodyne method. The pulsating current of the plate circuit is transferred by the feed-back method to the oscillating circuit through the action of coils *a* and *b*. The coupling between these coils should be rather close for successful operation, and the various adjustments in the coupled circuit must be accurately made. In other respects the principle of operation is not unlike the heterodyne method of reception.

The signals as received by an antenna are at best very weak, hence the amount of energy required to produce local oscillations of equal strength is consequently small. It is important when using the heterodyne method of reception, that a local current of approximately equal amplitude be combined with the incoming antenna current. This is also applicable to the autodyne method of reception, but as the oscillating current is necessarily small in this case, it is not apt to need special attention.

In the autodyne circuit the three-element electron tube is exhibiting three of its important functions, namely, those of acting as oscillator, detector, and to some extent as an amplifier, and these all simultaneously. The principle of feeding

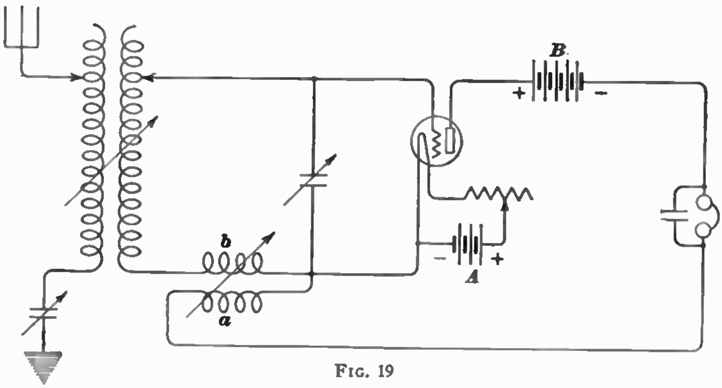


FIG. 19

some of the plate current back to the grid could probably be applied with advantage to other circuits using the three-element tube, especially those using one or more stages of radio-frequency amplification.

In the circuit of Fig. 19, as well as in others of a similar nature, the location of the *B* battery and telephone receivers could be interchanged with perhaps an improvement in operation. As the plate circuit carries a radio-frequency current, part of which is fed into the grid circuit, it is very probable that an improvement in operation will be secured by shunting the *B* battery by a condenser. This will provide a good path for the radio-frequency oscillations to the grid. A like result could be accomplished by connecting the condenser shunting the telephone receivers so as to include the *B* battery.

RADIO TELEPHONY

PRINCIPLES OF OPERATION

37. Radio telephony is the transmission of speech or other intelligible sounds by means of radio waves. In wire telephony the current-carrying medium is a metal conductor, while in radio telephony there is no visible connection between communicating stations. The electric waves in both wire and radio telephony are changed into audible sounds by means of suitable receiving apparatus; the sounds heard at the telephone receiver correspond with those at the transmitter in the sending station.

In radio telephony changes in the resistance of a circuit caused by sound waves striking the diaphragm of a transmitter in that circuit are used to modify the amplitude of the oscillations of a radio-frequency current. These modified oscillations are transmitted from station to station and by the aid of suitable apparatus at the receiving station, telephone receivers reproduce the sounds made at the transmitting station.

38. Modulation is the act of varying the amplitude of radio-frequency oscillations by the action of the audio-frequency changes established by the transmitter. In undamped-wave radio telegraphy, the outgoing oscillations are either interrupted or else detuned enough to produce dots and dashes of the telegraphic code. The outgoing oscillations in radio telephony are merely modulated or their outlines changed to correspond with the original sound disturbances.

Three methods for producing undamped waves of radio frequency, namely, by the use of the alternator, the arc, and the electron-tube oscillator, have been described, and any one of these may be employed for producing the radio-frequency carrier current. Only one typical arrangement will be illustrated and described for each of two of the systems.

39. Fig. 20 (*a*) represents an undamped wave of radio-frequency current such as would be produced by any of the devices just mentioned. View (*b*) represents approximately,

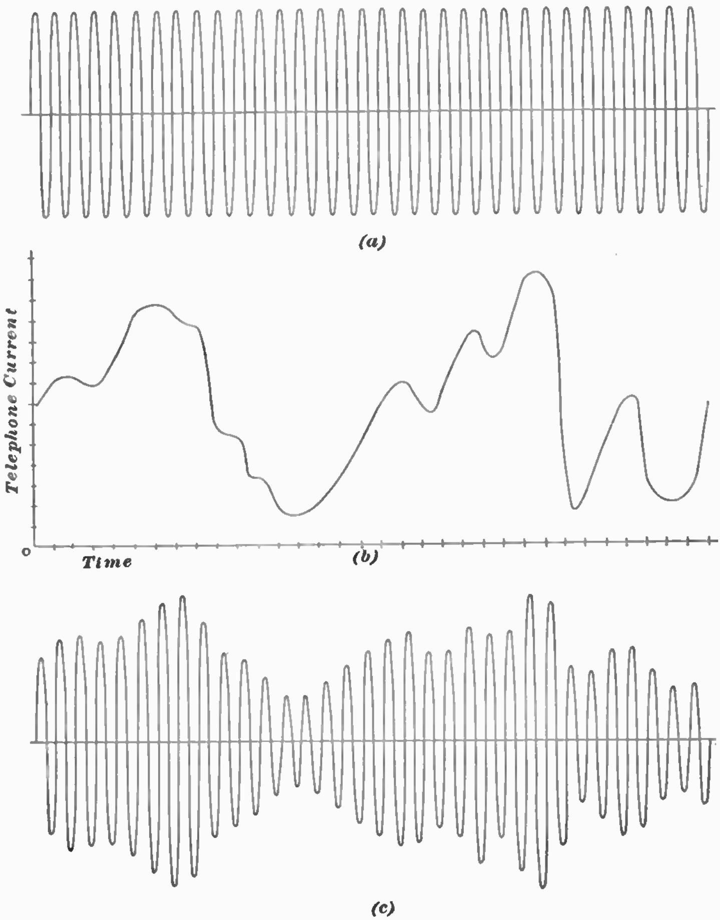


Fig. 20

the variation in current in a circuit consisting of a transmitter in action, a battery, and connecting wires. The current waves, view (*b*), as produced by the human voice are, in general, of irregular form. When the oscillations, view (*a*), are modified, by methods explained later, the outline of the modulated radio-frequency wave thus formed, view (*c*), assumes the general wave shape of the audio-frequency wave shown in view (*b*), but the high-frequency oscillations with modified amplitudes are still retained.

The undamped radio-frequency current, view (*a*), before modulation is sometimes called a *carrier current,* but the modulated radio-frequency current is the one actually transmitted. Its frequency is high enough to produce radio disturbances in the ether which will carry well and thus render communication over long distances possible.

TRANSMITTING CIRCUIT CONNECTIONS

ARC GENERATOR

40. Circuit arrangements for transmitting radio telephone signals or messages differ from those used in sending out undamped-wave radio telegraph intelligence in this respect, that the sending key used in producing dots and dashes of the telegraph code is replaced by a suitable device for modu-

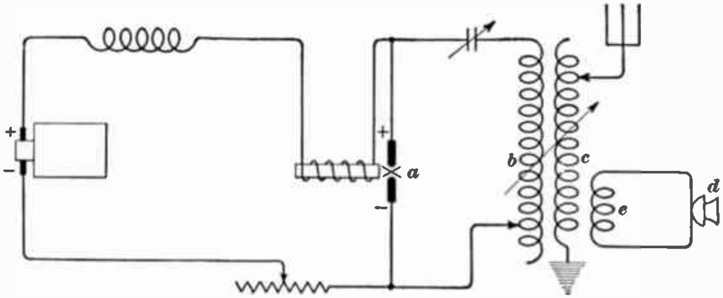


Fig. 21

lating the carrier current. The arc set *a* shown in Fig. 21, operates in the usual manner to produce undamped waves of radio-frequency. These oscillations in the inductance coil *b* are transferred by induction to coil *c* in the antenna circuit. An ordinary telephone transmitter *d,* when spoken into, produces variations in the resistance of its local circuit in accord with the changes in the sound waves impressed upon the diaphragm.

The inductance in the direct-current circuit supplying the arc tends to maintain the high-frequency current in the coil *c* as well as that in the other portions of the antenna circuit at nearly constant values when the transmitter is inactive. The telephone transmitter circuit is coupled to coil *c* by coil *e* and, therefore, even when the transmitter is inactive takes away a very small amount of the energy supplied to coil *c* by coil *b*. The amount of the energy taken by the telephone transmitter circuit depends on the resistance of this circuit. When the transmitter is active, the resistance of its circuit is varied and a variable amount of energy is supplied to it by coil *c*. Most of the remaining energy of coil *c* is radiated from the antenna circuit to the ether and the amount radiated is variable because of the variable amount of energy absorbed from coil *c* by the telephone-transmitter circuit. The amplitude of the radio-frequency oscillations is decreased when the amount of energy absorbed is increased and the amplitude of the oscillations is increased when the amount of energy absorbed is decreased. The energy radiated to the ether is thus modulated in accordance with the sound waves impressed on the transmitter diaphragm.

The arc set shown in Fig. 21 is merely one type of oscillator, and is often used in radio-telephone transmission. In place of the arc-generator set, however, a high-frequency alternator may be used, but an electron-tube oscillator is more commonly used than the two methods just mentioned for producing a high-frequency carrier current.

41. Although the transmitter circuit, Fig. 21, is shown coupled to the antenna circuit, such is not always the case. In practice, the transmitter may be coupled to other parts of the oscillating circuit, or even connected directly in series at certain places. For instance, a large current-carrying transmitter might be included in the antenna circuit, or several transmitters of the usual type could be connected in parallel in the same part of the circuit. Successful modulation has been accomplished by connecting the transmitter in the supply circuit, as, for example, in the field circuit of the Alexanderson alternator. As the current variations produced by the ordinary type of transmitter are often quite small, an amplifier is sometimes used to strengthen the variations before they are combined with the carrier current. It is impracticable to consider all the possible ways in which the audio-frequency waves are actually impressed on the carrier current. The fundamental principle to be applied is that the audio- and radio-frequency currents must act to form a radio-frequency current which carries the characteristics of the original sound wave; the exact method by which this is accomplished is unimportant, so far as the radiated wave is concerned.

USE OF ELECTRON TUBES

42. The electron tube, aside from its other important uses, is an excellent device for the absorption of energy. It is sometimes used in this connection in radio telegraphy, but the

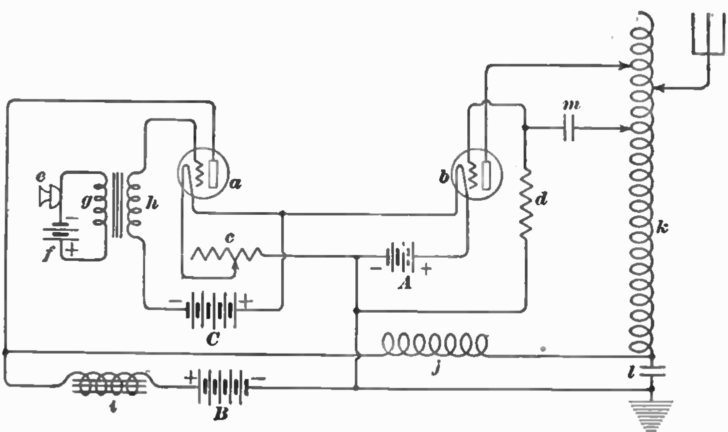


FIG. 22

more common case is in radio telephony to modulate the radio-frequency current generated by an oscillating tube. In the circuit of Fig. 22, the modulator tube *a* controls the plate current of the oscillating tube *b*. The filaments of the similar three-element electron tubes are connected in series, and supplied with current from a common *A* battery, which is controlled by an adjustable rheostat *c*. Likewise a common *B* battery furnishes a voltage for both plates in parallel. A *C* battery in the grid circuit of the modulator tube places a negative electromotive force on the grid. A slightly negative voltage is given to the grid of the oscillator tube *b* by the connection through a high resistance *d* to the negative terminal of the *B* battery. These negative voltages have been found necessary in order to force the tubes to operate steadily, and without distorting the signals. This is a very important feature in clear radio telephony.

A transmitter *e* with a local battery *f* is included in the circuit of the primary *g* of a transformer, whose secondary is at *h*. It is well to keep in mind the important fact that the electron flow is from the filament to the plate, while the plate current is assumed to be in just the opposite direction. The current from the positive terminal of the *B* battery passes through an inductance coil *i*, and then divides and passes to the two plates. The inductance coil *i* which has an iron core to increase its effect, maintains the current through itself practically constant.

A very irregular pulsating current is produced in the transmitter circuit when the diaphragm intercepts sound waves. By transformer action these pulsations are transferred to coil *h*, and then to the grid of the modulator tube *a*. If the effect of the voltage generated in the secondary coil *h* by the action of the transmitter is, at a given instant, such as to decrease the negative charge on the grid as compared to its condition when the transmitter was inactive, the plate current in the modulator tube will be increased because of the lessened opposing action of the negatively charged grid. The flow of electrons is thereby increased, therefore, the plate current is increased. The *B* battery furnishes a nearly constant current and if the plate current of tube *a* is increased, less current can pass to the plate circuit of the oscillator tube *b*. The plate circuit of the oscillator tube is connected to the antenna circuit and when the plate current is decreased, the amplitude of the radio-frequency oscillations radiated by the antenna is decreased.

43. If the action of the transmitter circuit, is, at a given instant, to increase the negative charge on the grid of the modulator tube *a*, the opposing action of the grid will be increased, the flow of electrons decreased, and, therefore, the plate current of tube *a* decreased. Because of the nearly constant current supplied by the *B* battery, more current will pass to the plate circuit of the oscillator tube *b*, and the amplitude of the radiated oscillations will be increased.

It is convenient to consider the variations of the grid voltage of the modulator tube as changing the resistance of the path between the plate and the filament in the tube. This change in the resistance causes a change in the division of current supplied to tubes *a* and *b* from the *B* battery.

It should be noted that any sound intercepted by the transmitter does not alter the frequency of, but modulates the outline of the radio-frequency oscillations. The modulation of the wave preserves the general characteristics of the original sound impressed on the transmitter.

44. The action of the inductance coil *i* prevents the audio-frequency plate-current pulsations of tube *a* from passing into the *B* battery, hence they follow the path through coil *j* to the plate of the oscillating tube. The coil *j*, which has less inductance than coil *i*, offers very little impedance or opposition to the audio-frequency variations, but quite effectually prevents the radio-frequency currents from leaving the antenna circuit, and becoming lost. The antenna coil *k* is equipped with several adjustable contacts. Tuning of the antenna proper is made by varying the contact of the movable antenna terminal. The series antenna condenser *l* may also be made variable for adjustments on short wave-lengths. Portions of coil *k* are used in conjunction with condenser *l* to form the oscillating circuit of the generator tube *b*. The grid of tube *b* in connection with the other portions of the oscillator-tube circuit enables the tube to establish a radio-frequency current. Condenser *m* prevents a shunt circuit for direct current between *d* and *k*, which are connected to opposite terminals of the *B* battery, but allows an oscillating current from the antenna inductance coil *k* to pass to the grid of tube *b*.

RECEIVING CIRCUITS

45. As was shown by view (*c*) of Fig. 20, the outline of the radiated wave corresponds to a large extent with the original sound wave. If the current is passed through a rectifier at the receiving station, one-half of the energy will be prevented from passing through the telephone receivers, and a pulsating current will result. The radio-frequency carrier current will be vibrating too fast to affect the telephone receivers. The audio-frequency pulsations, however, act upon the telephone receivers and accurately reproduce the original sound, with its characteristics practically unchanged.

46. It will be noted that the receiving set suitable for the reception of radio telephone messages is the ordinary damped-wave receiver circuit using a crystal or electron-tube detector. A suitable circuit connection is shown in Fig. 23, which follows the usual type of arrangement with a three-element electron tube *a* as the detector. The capacity of condenser *b* shunting the telephone receivers *c*, should be small so as not to distort the received signal pulsations.

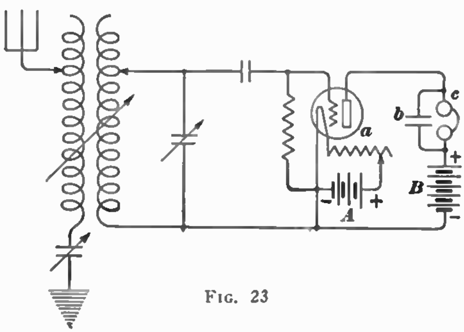


FIG. 23

TABLE 1
AVERAGE CHARACTERISTICS OF RECEIVING TUBES

	General							Detection				Amplification						
	Model	Use	Circuit Requirements	Base	"A" Supply	Filament Terminal Voltage	Filament Current (Amperes)	Detector Grid Return Lead To	Grid Leak (Meg-ohms)	Detector "B" Battery Voltage	Detector Plate Current (Milliamperes)	Amplifier "B" Battery Voltage	Amplifier "C" Battery Voltage	Amplifier Plate Current (Milliamperes)	A-C Plate Resistance (Ohms)	Mutual Conductance (Micromhos)	Voltage Amplification Factor	Maximum Undistorted Output (Milliwatts)
DETECTORS AND AMPLIFIERS	WD-11	Detector or Amplifier	Transformer Coupling	WD-11 Base	Dry Cell 1½V. Storage 2V.	1.1	.25	+F	3 to 5	22½ to 45	1.5	90 135	4½ 10½	2.5 3.5	15,500 15,000	425 440	6.6 6.6	7 35
	WX-12	Detector or Amplifier	Transformer Coupling	Large Standard UX Base	Dry Cell 1½V. Storage 2V.	1.1	.25	+F	3 to 5	22½ to 45	1.5	90 135	4½ 10½	2.5 3.5	15,500 15,000	425 440	6.6 6.6	7 35
	UX-112-A A	↓ Detector or Amplifier	Transformer Coupling	Large Standard UX Base	Storage 6V.	5.0	.25	+F	3 to 5	45	1.5	90 135	4½ 9	5.5 7	5,300 5,000	1,500 1,600	8 8	30 120
	UV-199	Detector or Amplifier	Transformer Coupling	UV-199 Base	Dry Cell 4½V. Storage 4V.	3.0 3.3	.060 .033	+F	2 to 9	45	1	90	4½	2.5	15,500	425	6.6	7
	UX-199	Detector or Amplifier	Transformer Coupling	Small Standard UX Base	Dry Cell 4½V. Storage 4V.	3.0 3.3	.060 .063	+F	2 to 9	45	1	90	4½	2.5	15,500	425	6.6	7
	UX-200-A	Detector	Transf. or Resist. Coupling	Large Standard UX Base	Storage 6V.	5.0	.25	−F	2 to 3	45	1.5	Following UX-200-A Characteristics apply only for Detector Connection			30,000	666	20	—
	UX-201-A	Detector or Amplifier	Transformer Coupling	Large Standard UX Base	Storage 6V.	5.0	.25	+F	2 to 9	45	1.5	90 135	4½ 9	2.5 3	11,000 10,000	725 800	8 8	15 55
	UX-222	↓ Radio Frequency Amplifier	Special Shielding (See Inst. Sheet)	Large Standard UX Base	Dry Cell 4½V. Storage 4–6V.	3.3	.132	—	—	—	—	135	1½ #	1.5	850,000	350	300 M	—
	UX-222	↑ Audio Frequency Amplifier	Resistance Coupling (See Inst. Sheet)	Large Standard UX Base	Dry Cell 4½V. Storage 4–6V.	3.3	.132	—	—	—	—	180 ‡	1½ □	.3	150,000	400	60	—
	UX-226	Amplifier A-C Filament Type	Transformer Coupling	Large Standard UX Base	Transformer 1.5V.	1.5	1.05	—	—	—	—	90 135 180	6 9 13½	3.5 6 7.5	9,400 7,400 7,000	875 1,100 1,170	8.2 8.2 8.2	20 70 160
	UY-227	Detector A-C Heater Type	Transformer Coupling	5 Prong Standard UY Base	Transformer 2.5V.	2.5 H	1.75	C	2–9 ¼–1	45 90	2 7	Following UY-227 Characteristic apply only for Detector Connection			10,000 8,000	800 1,000	8 8	— —
	UX-240	Detector or Amplifier	Resistance Coupling	Large Standard UX Base	Storage 6V.	5.0	.25	+F	2 to 5	135 ‡ 180 ‡	.3 .4	135 ‡ 180 ‡	1½ 3	.2 .2	150,000 150,000	200 200	30 30	—
	UY-224	Detector or Amplifier A-C Heater	Transformer Coupling	5 Prong Standard UY Base	Transformer 2.5V.	2.5	1.75	—	—	—	—	180	1½ S	4	400,000	1,050	420	—
POWER AMPLIFIERS	UX-112-A A	↑ Power Amplifier	No L. S. C. Required	Large Standard UX Base	Storage 6V. Transformer 5V.	5.0	.25	—	—	—	—	135 157½	9 10½	7 9.5	5,000 4,700	1,600 1,700	8 8	120 195
	UX-120	Power Amplifier	No L. S. C. Required	Small Standard UX Base	Dry Cell 4½V. Storage 4V.	3.0 3.3	.125 .132	—	—	—	—	135	22½	6.5	6,300	525	3.3	110
	UX-171-A A	Power Amplifier	L. S. C. Except at 90 V.	Large Standard UX Base	Storage 6V. Transformer 5V.	5.0	.25	—	—	—	—	90 135 180	16½ 27 40½	10 16 20	2,500 2,200 2,000	1,200 1,360 1,500	3.0 3.0 3.0	130 330 700
	UX-245	Power Amplifier	L. S. C.	Large Standard UX Base	Transformer 2.5V.	2.5	1.5	—	—	—	—	180 250	33 50	26 32	1,950 1,900	1,800 1,850	3.5 3.5	780 780
	UX-210	Power Amplifier	L. S. C.	Large Standard UX Base	Transformer 7.5V.	7.5	1.25	—	—	—	—	250 300 350 400 425	18 22½ 27 31½ 35	10 13 16 18 18	6,000 5,600 5,150 5,000 5,000	1,330 1,450 1,550 1,600 1,600	8 8 8 8 8	340 600 925 1,325 1,540
	UX-250	Power Amplifier	L. S. C.	Large Standard UX Base	Transformer 7.5V.	7.5	1.25	—	—	—	—	250 300 350 400 450	45 54 63 70 84	28 35 45 55 55	2,100 2,000 1,900 1,800 1,800	1,800 1,900 2,000 2,100 2,100	3.8 3.8 3.8 3.8 3.8	900 1,500 2,350 3,250 4,650

	Model	Use	Circuit Requirements	Base	Purpose		
RECTIFIERS	UX-213	Full-Wave Rectifier	Full-Wave Circuit	Large Standard UX Base	Rectification in Eliminators particularly Designed for this Radiotron	Filament Terminal Voltage..... 5 Volts Filament Current............ 2 Amperes A-C Plate Voltage........... 220 Volts } R M S (Max. per plate)	Max. D.-C Output Current (both plates)........ 65 Milliamperes D.-C Output Voltage at max. current as applied to filter of typical rectifier circuit........ 170 Volts
	UX-216-B	Half-Wave Rectifier	Half or Full Wave Circuit	Large Standard UX Base	Rectification in Eliminators particularly Designed for this Radiotron	Filament Terminal Voltage..... 7.5 Volts Filament Current.............1.25 Ampers A-C Plate Volatage............ 550 Volts } R M S (Max. per plate)	Max. D.-C Output Current........ 65 Milliamperes D.-C Output Voltage at max. current as applied to filter of typical rectifier circuit........ 470 Volts
	UX-280	Full-Wave Rectifier	Full-Wave Circuit	Large Standard UX Base	Rectification in Eliminators Designed for this Radiotron or Rectron UX-213	Filament Terminal Voltage..... 5 Volts Filament Current............ 2 Amperes A-C Plate Voltage........... 300 Volts } R M S (Max. per plate)	Max. D.-C Output Current (both plates)........ 125 Milliamperes D.-C Output Voltage at max. current as applied to filter of typical rectifier circuit........ 260 Volts
	UX-281	Half-Wave Rectifier	Half or Full Wave Circuit	Large Standard UX Base	Rectification in Eliminators Designed for this Radiotron or Radiotron UX-216-B	Filament Terminal Voltage..... 7.5 Volts Filament Current.............1.25 Amperes A-C Plate Voltage........... 750 Volts } R M S (Maximum)	Recommended / Maximum A.-C Plate Voltage........650..........700 Volts D.-C Output Current........ 65.......... 85 Milliamperes D.-C Output Voltage as applied to filter of typical rectifier circuit 620..........620 Volts
	UX-874	Voltage Regulator	Series Resistance	Large Standard UX Base	Constant Voltage Device	Designed to keep output voltage of B eliminators constant when different values of "B" current are supplied	Operating Voltage.......... 90 Volts Starting Voltage............ 125 Volts D. C. Operating Current..........10.50 Milliamperes
US	UV-876	Current Regulator (Ballast Tube)	Transformer Primary of 65 Volts for use on 115 Volt Line	Standard Mogul Type Screw Base	Constant Current Device	Designed to insure constant input to power operated radio receivers despite fluctuations in line voltage	Operating Current.......... 1.7 Amperes Mean Voltage Drop......... 50 Volts Permissible Variation....... ±10 Volts
	UV-886	Current Regulator (Ballast Tube)	Transformer Primary of 65 Volts for use on 115 Volt Line	Standard Mogul Type Screw Base	Constant Current Device	Designed to insure constant input to power operated radio receivers despite fluctuations in line voltage	Operating Current.......... 2.05 Amperes Mean Voltage Drop......... 50 Volts Permissible Variation....... ±10 Volts

↑ (↓) Note other use of this Radiotron above (below)
\# Inner Grid −1½ Volts; Outer Grid +45 Volts, .15 milliampere
□ Outer Grid −1½ Volts; Inner Grid +22½ Volts, 6 milliamperes
‡ Applied through plate coupling resistance of 250,000 Ohms
S Screen-Grid Voltage should be 75 Volts

NOTE: All grid voltages are given with respect to cathode or negative filament terminal

Max. Values not to be exceeded

A.....Except for half ampere filament, UX-112 and UX-171 characteristics are identical respectively to UX-112-A and UX-171-A.
C.....Cathode.
H.....Heater Voltage.
LSC...Loud Speaker Coupling, consisting of either Choke Coil and By-Pass Condenser or Output Transformer of 1:1 or step down ratio, recommended wherever plate current (D. C.) exceeds 10 milliamperes.
M.....With a screen-grid tube, on account of circuit limitations, the actual voltage amplification obtainable does not bear as high a relation to the voltage amplification factor as in the case of three-electrode tubes.

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TABLE II

TRANSMITTING TYPE THREE- AND FOUR-ELECTRODE TUBE DATA

Tube Type Number	Main Uses	Average Characteristic Values								Filament Data			Number of Electrodes	Approximate Direct Inter-Electrode Capacities in Mfd.			Type of Cooling	Max. R. F. Plate Dissipation Watts	Nominal R. F. Output Watts	Maximum Overall Dimension	
		At Following Voltages				Average Values															
		Filament Volts	Grid *Bias	Screen Volts	Plate Volts	Plate Ampere	Amplification Factor	Plate Resistance	Mutual Conductance	Type	Volts	Amperes		P-G	G-F	F-P				Length Inches	Diameter Inches
UX-841	Voltage Amplifier only........	7.5	−8		425	.0075	30	21,500	1,400	Thoriated	7.5	1.25	3	8	5	4	Air	15	7.5	$5\frac{5}{8}$	$2\frac{3}{16}$
UX-210	General Purpose.............	7.5	−39		425	.018	8	5,000	1,600	Thoriated	7.5	1.25	3	8	5	4	Air	15	7.5	$5\frac{5}{8}$	$2\frac{3}{16}$
UX-842	A. F. Amp. and Modulator....	7.5	−100		425	.028	3	2,500	1,200	Thoriated	7.5	1.25	3	8	5	4	Air	15	7.5	$5\frac{5}{8}$	$2\frac{3}{16}$
UX-865	R. F. Amplifier..............	7.5	0	125	500	.021	150	200,000	750	Thoriated	7.5	2.00	4	.05	10	7.5	Air	15	7.5	$6\frac{1}{4}$	$2\frac{3}{16}$
UX-250	A. F. Amp. and Modulator only	7.5	−84		450	.055	3.8	1,800	2,100	Ox. Coated	7.5	1.25	3	9	7	5	Air			$6\frac{1}{4}$	$2\frac{11}{16}$
UV-203-A	R. F. Amp. and Oscillator.....	10.0	0		1,000	.120	25	5,000	5,000	Thoriated	10.0	3.25	3	15	8	7	Air	100	75	$7\frac{7}{8}$	$2\frac{5}{16}$
UV-211	General Purpose.............	10.0	−55		1,000	.072	12	3,400	3,530	Thoriated	10.0	3.25	3	15	8	7	Air	100	75	$7\frac{7}{8}$	$2\frac{5}{16}$
UV-845	A. F. Amp. and Modulator....	10.0	−150		1,000	.075	5	2,100	2,380	Thoriated	10.0	3.25	3	15	8	7	Air	100	75	$7\frac{7}{8}$	$2\frac{5}{16}$
UX-852	R. F. Amp. and Oscillator only	10.0	0		2,000	.225	12	6,000	2,000	Thoriated	10.0	3.25	3	3	2	1	Air	100	75	$8\frac{3}{4}$	Rad. $4\frac{1}{4}$
UX-860	R. F. Amplifier only..........	10.0	0	500	2,000	.085	200	150,000	1,350	Thoriated	10.0	3.25	4	.05	8.5	9	Air	100	75	$8\frac{3}{4}$	Rad. $4\frac{1}{4}$
UV-853	R. F. Amp. and Oscillator.....	10.0	0		2,000	.170	12	3,500	3,000	Tungsten	10.0	16.25	3	17	18	3	Air	250	250	$14\frac{3}{8}$	$4\frac{1}{16}$
UV-204-A	R. F. Amp. and Oscillator....	11.0	0		2,000	.275	25	5,000	5,000	Thoriated	11.0	3.85	3	17	18	3	Air	250	250	$14\frac{3}{8}$	$4\frac{1}{16}$
UV-849	General Purpose.............	11.0	−132		3,000	.100	19	3,200	6,000	Thoriated	11.0	5.00	3	35	20	4	Air	400	350	$14\frac{3}{8}$	$4\frac{1}{16}$
UV-861	R. F. Amplifier only..........	11.0	0	750	3,000	.172	300	133,000	2,250	Thoriated	11.0	10.00	4	.05	17	13	Air	400	500	$17\frac{7}{32}$	Rad. $6\frac{5}{8}$
UV-851	General Purpose.............	11.0	−65		2,000	.300	20	1,400	15,000	Thoriated	11.0	15.50	3	55	30	7	Air	750	1,000	$17\frac{5}{8}$	$6\frac{1}{8}$
UV-206	R. F. Amp. and Oscillator only	11.0	0		10,000	.025	350	300,000	1,170	Tungsten	11.0	14.75	3	11	10	1	Air	350	1,000	$15\frac{1}{2}$	$5\frac{1}{16}$
UV-854	General Purpose.............	14.5	−515		10,000	.750	14	2,900	4,800	Tungsten	14.5	52.00	3	27	18	2	Water	10,000	10,000	$20\frac{1}{4}$	$4\frac{5}{32}$
UV-863	R. F. Amp. and Oscillator only	22.0	−20		10,000	.750	50	7,200	7,000	Tungsten	22.0	52.00	3	27	18	2	Water	10,000	20,000	$20\frac{1}{4}$	$4\frac{5}{32}$
UV-207	General Purpose......	22.0	−310		10,000	.750	20	3,500	3,300	Tungsten	22.0	52.00	3	27	18	2	Water	10,000	20,000	$20\frac{1}{4}$	$4\frac{5}{32}$
UV-848	A. F. Amplifier..............	22.0	−1,000		10,000	.750	8	2,400	2,800	Tungsten	22.0	52.00	3	27	18	2	Water	10,000	20,000	$20\frac{1}{4}$	$4\frac{5}{32}$
UV-862	R. F. Amplifier..............	33.0	−35		18,000	3.0	48	2,800	17,150	Tungsten	33.0	207.00	3	80	52	2	Water	100,000	100,000	5′ $\frac{3}{8}$″	$6\frac{1}{8}$

*With respect to mid-point of filament.

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