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Radio Receivers and Transmitters

182 Illustrations

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COMMERCIAL VACUUM TUBES
CONSTRUCTION OF RECEIVING SETS
RADIO-FREQUENCY AMPLIFICATION
AUDIO-FREQUENCY AMPLIFICATION
BROADCAST RECEIVING SETS
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Published by
INTERNATIONAL TEXTBOOK COMPANY
SCRANTON, PA.
1927

Printed in U. S. A.

PRESS OF
INTERNATIONAL TEXTBOOK COMPANY
SCRANTON, PA.
450

90853

PREFACE

The volumes of the International Library of Technology are made up of Instruction Papers, or Sections, comprising the various courses of instruction for students of the International Correspondence Schools. The original manuscripts are prepared by persons thoroughly qualified both technically and by experience to write with authority, and in many cases they are regularly employed elsewhere in practical work as experts. The manuscripts are then carefully edited to make them suitable for correspondence instruction. The Instruction Papers are written clearly and in the simplest language possible, so as to make them readily understood by all students. Necessary technical expressions are clearly explained when introduced.

The great majority of our students wish to prepare themselves for advancement in their vocations or to qualify for more congenial occupations. Usually they are employed and able to devote only a few hours a day to study. Therefore every effort must be made to give them practical and accurate information in clear and concise form and to make this information include all of the essentials but none of the non-essentials. To make the text clear, illustrations are used freely. These illustrations are especially made by our own Illustrating Department in order to adapt them fully to the requirements of the text.

In the table of contents that immediately follows are given the titles of the Sections included in this volume, and under each title are listed the main topics discussed.

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NOTE.—This volume is made up of a number 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.

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(Continued)

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RADIO-TELEPHONE TRANSMITTERS
(Continued)

COMMERCIAL VACUUM TUBES

TUBES FOR RECEIVING SETS

INTRODUCTION

1. Some information has been given on the principles governing the operation of electron tubes. The fundamental principles apply to any type of two- or three-element tube, so they will not be repeated here except for the sake of clearness at certain points. Some additional information will be given to explain the electrical and other characteristics of some of the common tubes and the effects of such characteristics on the operation of a tube in a radio set. Information will be given on the main characteristics of some of the more important types of commercial radio tubes, especially those used in the reception of radio communication signals

CLASSIFICATION OF TUBES

2. Radio receiving tubes may conveniently be divided into groups, according to the type of filament. These are tungsten, oxide coated, and activated. They may also be subdivided into smaller groups, depending upon the amount of current or energy that is required to heat the filament.

The earlier types of commercial tubes used filaments made of practically pure tungsten, as this was the most convenient material. To get a satisfactory electron emission with a filament of this type, it is necessary to keep the filament at a rather high temperature. This tends to burn the filament up rather rapidly and also weakens the filament while it is incandescent, thus increasing the liability of breakage. Filaments of this type must be made rather large to have a reasonably long life, and under such conditions take a fairly large filament current. If the filament size were reduced to decrease the current, the life of the filament would be reduced excessively.

3. Coating a wire with certain materials aids the liberation of the electrons from the filament or wire. This increase in the number of emitted electrons occurs to a considerable extent at temperatures much below that required for satisfactory emission from pure tungsten filaments. In fact, with some types of coating, a satisfactory emission will be obtained at such a temperature that the filament barely glows. This, in general, means that the life of the filament is much longer than it would be otherwise.

The exceptional emission obtainable from coated filaments has resulted in the development of tubes operable at very small filament current and voltage values. The coated-filament type of tube may be made with the larger current rating, in which case the tube will give a life of several thousand hours.

4. Certain materials, such as thoria, when combined with the filament metal cause the filament to give off electrons much more freely than when it is made of pure metal. This is especially true after the filament has been properly treated. When the proper material is combined with the filament, it will emit electrons at a temperature much below that which would be required with the pure filament metal. This is conducive to long life of the filament in operation. It is also possible to utilize this type of filament in sizes that are very small and that require very little energy to heat the filament. The thoriated filament may be utilized in the large-sized power tubes with a consequent improvement in operation, and a decreased expenditure of filament energy.

PURE METAL FILAMENT TUBES

EARLY TYPES OF FILAMENTS

5. Early studies of two- and three-element electron tubes were made with pure metal filaments similar to those used in electric lamps at that time. This metal was chiefly tungsten, as it is readily workable to fine sizes and stands very high temperatures. When operated at such temperatures, corresponding roughly with incandescence, the tungsten filament emits a fairly large number of electrons. Furthermore, the filament will last a comparatively long time if the temperature is not allowed to become excessive.

EARLY CYLINDRICAL PLATE TUBES

6. The pure metal filaments were drawn to the right size and used in proper lengths to give the correct operating temperature when connected across a 6-volt storage battery. One of the simplest and most satisfactory methods of mounting the filament was in a straight line between two fairly heavy support wires. The filament then often formed the axis of the cylindrical grid and plate elements, at least in so far as the relative positions of the elements were concerned. With the short filament and large clearance customary between the elements, the characteristics were not any too good, but at that the results obtained were far in advance of those obtainable by other available means. The degree of vacuum was not very uniform nor high, so the plate voltage often was critical in adjustment, especially with tubes used as detectors. The amplification of signals was also possible with such tubes that had a good vacuum.

OTHER EARLY TUBE DESIGNS

7. The straight-filament tubes were made in many styles and designs. Sometimes the filament and other elements were placed horizontally in the tube and other times they were

vertically located. In a few cases the filament was placed close to a flat grid with a flat-plate element just beyond. In other early types of construction the filament was coiled either spirally or helically with the grid and plate so designed and located as to have good characteristics. The leads or connection wires were taken out at various parts of the tube by different manufacturers. There were many types of bases used in the early tubes, but the styles have been reduced to a small number in most of the countries. In some few cases the third element was placed outside the bulb and connected as a grid or plate in various types of circuits. This made such an inferior tube that it was not extensively adopted.

UV-201 TUBE

8. One of the early radio tubes that had wide use, especially as an amplifier, was known as the UV-201 tube. These letters and figures merely designate the type. This tube, like some others, had a 1-ampere filament rated to operate at 5 volts. This rating necessitates the operation of the filament from a 6-volt storage battery with a 6-ohm rheostat to secure proper filament control. The UV-201 tube is illustrated in the two views (*a*) and (*b*) of Fig. 1. The tube is shown mounted in what has often been called the standard American bayonet base. It is called the C-301 by one manufacturer, but has practically the same electrical and mechanical characteristics.

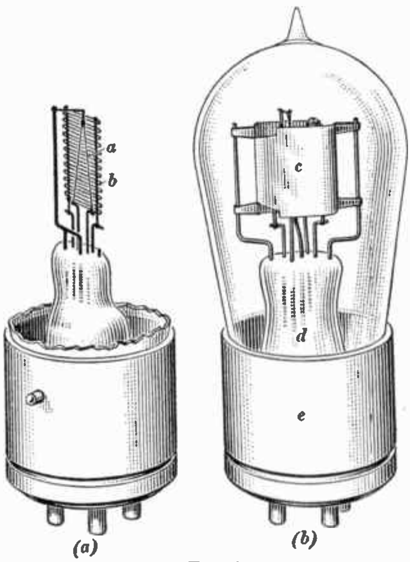


Fig. 1

The filament is visible in the illustration at *a*, view (*a*), and is supported so as to form an inverted **V** with its two connecting wires passing out of the bottom of the tube. The grid *b* is flattened so as to be as close as possible mechanically to the main part of the filament. The plate *c*, view (*b*), is shaped similarly to the grid, and forms a sort of oval enclosure around the grid and filament elements. Extensions on the plate are clamped around the support wires, one of which is connected with the circuit outside by an extension through the specially shaped section of glass *d*. The section of glass *d* through which the lead wires pass is known as the *press*. The whole tube is mounted in a brass and porcelain base *e* containing four pins in the bottom for making connection with a socket designed for such use.

9. The UV-201 radio tube is a *hard* type of electron tube; that is, it has a high degree of vacuum. This is secured by pumping out as much air as is conveniently possible, then using some material, such as phosphorus, to carry the evacuation to a higher degree. With practically no gas left in the tube there is no appreciable ionization to cause an auxiliary electron emission, so that that emission cannot affect the operation of this tube, as is the case with some other types of tubes. The total emission or electron current must come from, and be limited to some extent by, the filament. With the rated filament potential of 5 volts this electron current depends primarily on the plate voltage. The plate current also is affected by the grid voltage, or, more properly, the grid bias, and by the resistance of the apparatus connected in the plate circuit.

The filament in this type of tube is made of tungsten and is quite rugged. The life of the filament, and consequently of the whole tube, is prolonged if the 5-volt rating is not exceeded. If the filament is burned at a higher temperature, it wastes away or is eaten up very rapidly, while the life is greatly increased if the tube is burned at a low temperature. The end of the useful life of tungsten-filament tubes is not generally reached until the filament burns out or is broken in some way.

Since the filament is of pure tungsten, the emission from the UV-201 tube is not especially high. The emission is determined by connecting the grid and plate together, and reading the resulting current caused by the rather high plate voltage. However, the plate-current curve of this tube is quite satisfactory and gives a good indication of the properties of the tube. The other electrical characteristics are also good and combine to make this tube useful in general radio work.

10. The UV-201 tube makes a good detector of radio-frequency signals, when used with a grid condenser and grid leak. The grid condenser should have a capacity close to .00025, or it may be as high as .0005, microfarad. The grid leak should have a resistance of from 1 to 3 megohms, or 1,000,000 to 3,000,000 ohms, although lower resistance values may be used, especially on strong signals. When so used this tube will operate reliably, and will not require a critical adjustment of plate voltage to secure good results. A plate potential of 20 to 40 volts will be satisfactory for the detector tube.

The plate-current curve of this tube varies in a manner to give a straight-line characteristic; that is, the changes of plate current are directly proportional to the grid-voltage changes over a large range of grid-potential values. The tube, therefore, makes a good amplifier, and, it amplifies without appreciable distortion over a considerable range of signal strengths. Very often in audio-frequency work a small grid bias will increase the energy amplification, and reduce the distortion by causing operation on a better part of the characteristic curve. The grid-bias value will increase as the plate voltage is raised, and is especially effective with the higher plate potentials. As the output is directly dependent on the emission, it is desirable to use the tube at its rated filament voltage unless satisfactory signal strength is secured with lower filament temperatures. In radio-frequency amplification a grid bias should be used to limit the plate current if possible. Often radio-frequency amplifiers require a potentiometer to stabilize operation by introducing a positive grid bias.

The UV-201 tube operates very well as an oscillator, when properly connected, and when operated at rated filament and plate voltages. The plate should not be allowed to get so hot as to melt, when the tube is used as an oscillator, and a lower reddish operating temperature is to be recommended. A change in the coloring on the inside of the bulb during life does not affect the operation in any way.

UV-200 TUBE

11. The UV-200 tube, which is called the C-300 tube by one manufacturer, is used quite extensively as a detector. A certain amount of gas is either left in the tube or introduced during manufacture. During operation the gas is ionized by the electrons in the plate circuit, and this ionization of the gas is largely responsible for the successful operation of the tube as a detector. A rather critical adjustment of the conditions governing ionization is necessary.

The UV-200 tube is ordinarily made with a filament taking 1 ampere with a potential of 5 volts. This tube, therefore, requires a storage battery as the source of current supply. A 6-ohm rheostat is satisfactory as a filament-current control since less than 5 volts must be impressed on the filament in some cases. A vernier adjustment on the rheostat is also nearly a necessity, to give minute filament control. The plate voltage for best operation is in the range of 16 to 22 volts.

The UV-200 is in construction similar to the UV-201 tube. The grid is a sort of flattened oval construction supported by posts at each edge of the flattened section. The plate is also flattened so as nearly to enclose the filament and grid assembly, with a certain small clearance from the grid. Small extended pieces of the plate are attached to rigid supports on either side.

12. A condenser of .00025- to .0005-microfarad capacity is usually placed in the grid lead when the UV-200 tube is used as a detector or rectifier of radio-frequency currents. The plate current is controlled by the grid voltage or potential, and an audio-frequency current change is produced in the plate circuit. Some of the electrons forming the plate current collide with some of the gas atoms left in the tube. This collision, if of sufficient force, disrupts the atom into a positively charged ion and frees some negatively charged electrons. The ions pass to the filament, while the negatively charged electrons serve to augment the electron flow. When the plate voltage and other operating conditions are just right the tube is most sensitive, owing primarily to the proper ionizing conditions. The plate-voltage adjustment is so critical that a potentiometer is often connected in the negative *B*-battery lead, to provide for accurate settings, even if a tapped *B* battery is used.

The main and vernier controls of the filament current by the rheostat often assist materially in adjusting the tube to a condition of maximum sensitivity. Because of the presence of the gas in the tube, any negative charge that may accumulate on the grid can pass to the filament without the necessity for a separate grid leak shunting the grid condenser. Occasionally, however, a grid leak of .5 to 2 megohms will aid operation, especially if some of the gas is burned up by the filament during life. The UV-200 tube is commonly known as a *soft* type of detector tube owing to the presence of gas in the tube. It is important to note that the grid return lead should connect with the negative filament lead when the UV-200 or any other soft or gassy tube is used as a detector.

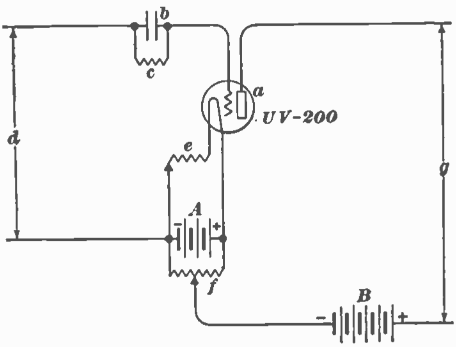


FIG. 2

13. The connections of a UV-200 tube are indicated in Fig. 2. The grid of the tube *a* has the grid condenser *b*, also the grid leak *c* connected as shown. The leads at *d* connect with the tuner or other input device. It should be noted that the grid-return connection is made to the negative *A*-battery lead. The rheostat *e* should be of a vernier type for accurate filament-current control. The potentiometer *f* should have a resistance of 200 to 400 ohms and be connected across the *A* battery. The slider of the potentiometer is connected with the negative *B*-battery lead and serves to provide accurate plate-voltage control. The two leads *g* connect with the output circuit.

COATED FILAMENTS

14. The coated filament is the result of an attempt to increase the electron emission over that obtainable from a pure wire filament. The coating generally takes the form of oxides adhering directly to the filament. Barium and strontium and other materials have been used as the basis of the coating. These materials are mixed with a binder to cause them to stick to the wire, which is coated with several layers of the material.

The treated filament must be handled with extreme care to prevent rubbing off some of the coating. Very often flat wire is used, as such wire has a larger surface than round wire for a given cross-sectional area, and consequently produces a greater emission.

15. With most types of oxide coating, a large electron emission may be secured when the filament is at such a temperature that it barely reaches a reddish glow or color. At this temperature the filament life is comparatively long. The coating on the filament keeps it at a uniform temperature, and the coating should change uniformly during normal burning. Accidental injury or high temperature will sometimes cause holes in the coating, which often show up as hot spots or points of greater brightness in the filament. With continued burning, this point of high temperature is apt to decompose rapidly and eventually result in burning out the filament. Unless defective in some other way, the oxide-coated filament will retain a relatively high electron emission throughout its life.

OXIDE-COATED FILAMENT TUBES IN COMMERCIAL FIELD

16. Many of the earlier types of American commercial oxide-coated filament tubes were made for governmental and telephone work. These fields called for many specialized types with widely different characteristics to cover the various requirements. Some of these types, or others with similar properties, are still on the market, and are occasionally used in radio sets where special conditions are to be met, or particular results are desired. These tubes have for the most part been designed for storage-battery filament operation. They vary in characteristics from those with an amplification factor of over 30 with a correspondingly high plate-circuit impedance, to others with an amplification factor of just over 2 and a relatively low plate-circuit resistance. Particular care is necessary in using such tubes in radio circuits to secure the best results.

WD-11 TUBE

17. Description.—The WD-11 tube is one of the most widely used oxide-coated filament tubes. This same type of tube is made by another manufacturer as the C-11 tube, and when equipped with a standard bayonet base is known as the WD-12 tube and the C-12 tube. The WD-11 tube normally is equipped with a distinctive bakelite base and a special base-pin arrangement to minimize the danger of placing the tube in a socket wired for filament voltages that would prove unsafe for this tube. Adapters are also available which make it possible to use the WD-11 direct with a socket designed to take the standard bayonet base. An external view of the WD-11 tube is shown in Fig. 3.

The filament size is such that the best operating temperature is secured with a filament current of .25 ampere. The filament length is made so that a voltage of 1.1 is necessary to send this current through the filament. This relatively small amount of filament energy will not run down a regular No. 6 dry cell very rapidly. In fact, the filament was largely designed for operation from such a battery source. When more than one

WD-11 tube is in use, an equal number of dry cells should be connected in parallel as the battery supply for the filaments of all the tubes. Also separate dry cells may be connected to the individual tubes if that arrangement is more convenient. This type of tube will work equally well when the filament current is supplied by a storage cell. Extreme care must be exercised to see that there is sufficient resistance connected in the filament circuit to keep the filament current at a safe value. More than a 2-volt storage cell should not be employed as a filament supply, owing to the liability of applying an excessively high voltage to the filament.

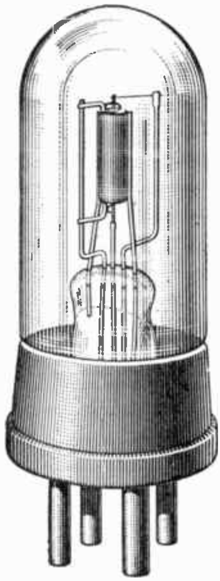


FIG. 3

18. Operation of WD-11 Tube.—In operation, successful results are generally secured by a lower filament temperature than is represented by the rated conditions. The lower filament current and voltage will give a longer life, so should be used whenever possible. During manufacture, the platinum filament is coated with certain oxides that cause it to give off a very large number of electrons compared with the number that would be emitted by the platinum metal itself. This oxide coating produces a satisfactory emission with the filament at a dull red glow that is scarcely visible.

The end of the useful life usually does not occur until the filament burns out or becomes broken, although the tube may become inoperative for other reasons. The burn-out at normal voltage sometimes starts with a so-called hot spot, at which point the coating is apparently broken through. After such a hot spot develops, the tube may give considerable service, especially if the filament voltage is kept low. A high voltage, such as that of a *B* battery, will probably burn out the filament instantly. It is good practice to remove the tubes while making circuit changes in the set.

A 6- or 10-ohm rheostat is satisfactory for controlling the filament current or voltage. In some radio sets the tube filaments are controlled by one common rheostat with good results. The glass bulb of the WD-11 tube is not discolored during manufacture by most manufacturers. Some material that helps the exhaust conditions may be painted on the glass stem during manufacture, but this can do no harm in the tube. The elements of the tube are subject to vibration if the tube is rigidly mounted in the set. In some individual tubes this vibration is great enough to cause considerable noise in the loud speaker, especially if the detector tube happens to be noisy and this noise is increased or amplified by the following amplifier tubes. It is good practice to mount all the sockets, especially that containing the detector tube, on rubber or other cushions to prevent jars from affecting the tube elements. It is also advisable to mount the tubes so that they are vertical, that is, so that the plate is in a vertical position.

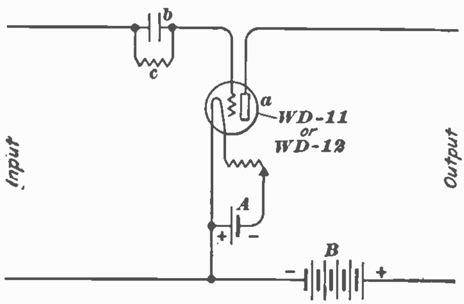


FIG. 4

19. WD-11 Tube Used as Detector.—The WD-11 tube is a good detector of radio-frequency signals. It should be used with a grid condenser having a fixed capacity of .00025 microfarad. Since the tube is practically free from gas, it requires a grid leak to prevent a negative charge from accumulating on the grid. The characteristics of this particular tube are such that a grid leak of at least 3 megohms (3,000,000 ohms) is required. Grid leaks of different values should be tried until one is found that will cause the set to go into and out of an oscillating condition smoothly and steadily. A plate potential of 20 volts is satisfactory for detector action. Higher than 22 volts usually will not give much stronger signals, and potentials greater than 44 should not be used. A separate filament rheostat for the detector tube is often convenient in securing fine tuning results, but is by no means essential. The grid return of the tube *a*, Fig. 4, is, as it should be, connected with the positive *A*-battery terminal. The grid condenser *b* and grid leak *c* are also shown as is the *B* battery, properly connected. Leads to the left and right connect with the input and output circuits, respectively.

20. WD-11 Tube Used as Amplifier.—The WD-11 tube has characteristics which make it a good amplifier of both audio- and radio-frequency currents. The operation of the tube then depends upon its plate-current characteristic, which is very good, as this type of tube has a good electron emission. A fairly high emission will ordinarily give a rather steep plate current grid-voltage characteristic curve, so that the changes of voltage applied to the grid will produce relatively large changes in the plate current. The design of the elements of the tube,

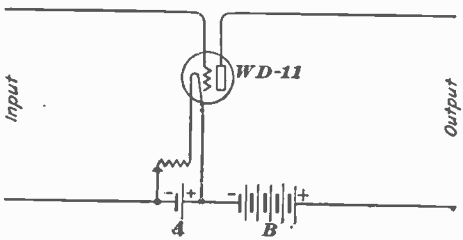


Fig. 5

and their spacing, are such that it has a reasonably high amplification factor and a fairly low plate-to-filament impedance, properties that make the tube a good amplifier. The elements are so close together that they are apt to get shorted with or to touch each other, if mishandled, which renders the tube inoperative.

21. The WD-11 tube will operate as an audio-frequency amplifier with about 44 volts on the plate. Since this is a high-vacuum type of tube the plate potential is not critical, although the higher voltages give the stronger signals. The grid return on the amplifier tube should connect with the negative end of the filament, as this will tend to cause the tube to operate over the proper part of its characteristic curve. A slightly better arrangement is to connect the grid return to the negative terminal of the battery with the filament-control rheostat in the negative lead. This will cause any voltage drop in the rheostat to act as a grid bias to give operation over a better part of the characteristic curve. This latter circuit connection is illustrated by Fig. 5. A grid-bias, or *C*, battery should be connected in the grid-return lead to prevent distortion when higher plate voltages are used. The *C* battery should be connected as shown in Fig. 6. with its negative terminal toward the grid. Small 1.5-volt dry cells may be used for this purpose, and there should be one cell less than there are units of 22.5-volt *B* battery. Plate potentials higher than about 120 volts will generally not improve the operation a great deal, and are seldom used.

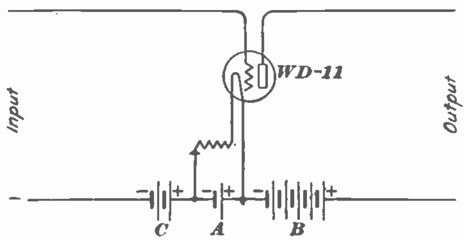


FIG. 6

22. In radio-frequency amplification work, plate voltages of 66 to 88 volts are commonly used. The characteristics of this tube are such that it tends to oscillate under these conditions, especially when the various circuits are tuned. Instead of a negative grid bias, a positive bias is often applied to the grid of a radio-frequency amplifier, by means of a potentiometer connected across the *A* battery. While this tends to produce a little distortion, it relieves the more vexatious trouble of oscillation, by introducing some losses into the circuit. If the circuit can be adjusted so as not to produce oscillations, it is well to employ a *C* battery to limit the plate current as much as possible.

COMBINED FILAMENTS

GENERAL CONSIDERATIONS

23. The electron emission from the filament of a radio tube may be increased by introducing a suitable material directly into the metal from which the filament is drawn. A compound or form of thorium, for instance, when diffused through the filament wire during manufacture, may later be brought to the surface of the tube filament. Among other desirable features, thorium has the property of high emissivity, that is, it will give off a very large number of electrons at a fairly low operating temperature.

The thorium compound, generally containing not more than 2 or 3 per cent of thorium, is combined with pure tungsten or other filament material, which is later drawn to the desired diameter. Special precautions are essential to see that the filament, especially the thorium compound, is not contaminated. After the tube is exhausted, it is treated so as to bring some of the thorium to the surface, thus making it available for furnishing a large supply of electrons. An ample emission is provided by the thorium at a temperature so low that very few electrons would be given off by the pure tungsten filament.

24. The rapid emission of electrons diminishes the supply of thorium at the surface. However, if the filament is operated at the proper temperature, the thorium inside the filament will gradually come to the surface, and keep a constant supply of electron-emitting thorium always available. The thorium is a rather unstable compound, and has a lower temperature of evaporation than does tungsten. This low temperature of evaporation is the property that produces the relatively high electron emission. If the thoriated filament is burned at too high a temperature, the thorium at the surface is evaporated faster than it is replenished by that inside the filament. This will soon result in a noticeable drop in emission, or, if the temperature is excessive, the tungsten may emit a large electron current that will continue until burn-out occurs.

If the high filament temperature has not been maintained for too long a time, it is generally possible to revive the filament by burning it about two hours at normal or rated temperature, with the plate voltage and, if possible, the grid lead, disconnected. This allows some of the thorium to reach the surface of the filament, and, since there is no *B* battery connected, there will be an accumulation of electron-emitting thorium on the filament. If a rather high voltage has caused the tube to become inoperative, a longer period of burning will be necessary to revive the filament. If the filament has been badly mistreated it may be necessary to use more drastic methods to revive it. When other methods fail, burning the filament a short period, say one-half minute, at about double-rated filament voltage followed by two hours at normal filament voltage will often give results. This treatment should be done with the plate voltage disconnected. It is good practice to disconnect the grid too, when treating the filament.

25. One of the great advantages of the thoriated filament over pure wire filaments lies in the fact that the relatively high emission may be secured with a lower value of filament energy. This represents an actual saving, since the energy expended by the filament does not directly affect the loudness of signal produced by the tube. The thoriated filament wire need not be so large in diameter as a pure tungsten filament, because the thoriated filament requires a much lower operating temperature of the filament.

At the proper operating temperature the life of the filament is very long. In fact, the end of useful life will occur, usually not by burn-out but by a considerable decrease in the electron emission.

Another desirable feature, but which is not so apparent, is the fact that the thoriated filament is somewhat longer than a pure tungsten filament to operate under similar conditions. This greater filament length permits of better electrical design of the tube as a whole, especially as regards its amplifying power.

UV-201-A TUBE

26. Construction of UV-201-A Tube.—The UV-201-A tube is one type of radio receiving tube that has a thoriated filament. It is also largely marketed as the type C-301-A, and many other symbols have been applied to tubes quite similar in their characteristics. The UV-201-A tube is designed to operate with a potential of 5 volts applied to the filament. Under this condition the filament current is close to .25 ampere, and either the voltage or the current value may be used in determining the proper operating conditions. This amount of filament energy is smaller by far than that required by some other types of tubes. While a single UV-201-A tube may be operated from dry cells, the life of the cells will be rather short. This tube is primarily designed to operate from a storage battery, and will do so with a minimum drain on the battery; in fact, four of these tubes will take no more filament energy than did one of the older tubes, namely, the UV-201, which the UV-201-A has largely replaced.

The usual 6- to 10-ohm rheostat will be found satisfactory for controlling the filament current and voltage, although a higher resistance for the rheostat is more desirable. A vernier adjustment on the detector-tube rheostat is often an aid in tuning the set accurately to weak signals. Most types of carbon-pressure rheostats are especially good, as they give uniformly fine adjustments of filament current over a wide range of values. The characteristics of the tubes are near enough alike so that one rheostat may be used on two or more amplifier tubes, but individual filament control is very desirable on the detector tube. The UV-201-A tube is mounted in the standard large bayonet base, and is interchangeable with similar tubes. The usual four pins in the base are arranged in the standard fashion and connect with contact springs in the sockets. A small pin on the side of the base guides the tube into the socket, and holds the base in place.

27. The UV-201-A radio tube is shown in Fig. 7. In view (*a*) only the elements of the tube are shown. The greater portion of the one side of the plate *a* has been removed to show the grid *b* and the filament *c*. The filament has the form of an inverted **V** and is held at the apex by a support that is insulated from the rest of the filament and also from the other elements. This extra support keeps the filament in position and prevents it from coming in contact with the grid. The fairly heavy support wires, such as *d*, are all mounted in the glass press, which holds the elements in their proper relative positions. Four of the lead wires go through the glass in the press and are soldered to the pins in the bottom of the base. The complete tube is shown in view (*b*).

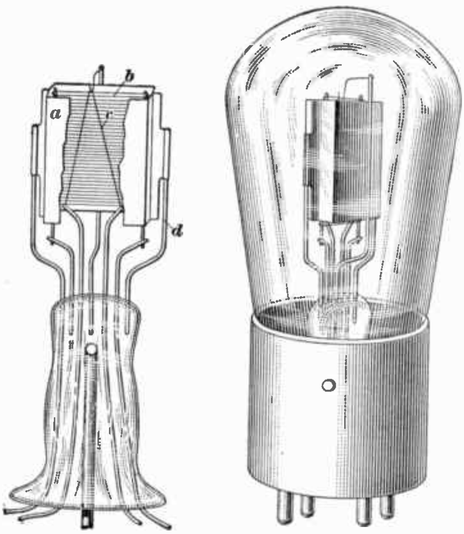


Fig. 7

28. A thoriated tungsten filament is used in the UV-201-A radio receiving tube. This means, among other things, that it has a very high electron emission, with the filament burned at a rather low temperature. So long as this temperature is maintained, there will be a satisfactory supply of electrons throughout the useful life of the tube. If the rated voltage is exceeded, the tube may become inoperative temporarily. If such is the case, it may often be revived by burning the tube about two hours with the plate battery disconnected. In practice, it is often possible to reduce the filament voltage and current considerably below the rated values and still secure good signals. Whenever possible, this should be done, as it prolongs the life of the filament and also effects an appreciable saving in both *A*- and *B*-battery energy by reducing the current drain. As has been indicated, an excessive filament burning temperature will, if maintained for some time, soon destroy the special activation of the filament, and tend to reduce the operable life very materially.

The thoriated tungsten filament is rather subject to contamination if air comes in contact with it. This will result in a decrease in the emission, which can frequently be revived by the methods already described. Ordinary methods do not suffice for securing a vacuum in the tube during manufacture, as there are many atoms of gas actually left inside the bulb with most types of exhaust pumps. A special method of treatment is employed to help secure a more nearly perfect vacuum than would be obtained otherwise. This process generally discolors the bulb to a greater or less degree, but this does not have any injurious effect on the operation of the tube in a set.

29. The grid is mounted rigidly so as almost to enclose the filament, the better to control the flow of electrons from the filament to the plate. Very little clearance is allowed between the filament and grid, so extreme care in handling is essential to prevent short-circuiting these elements. The design and dimensions of the grid are of extreme importance in determining the amplifying power of the tube as a whole. The plate is made of a thin sheet of metal, and designed to practically enclose the filament and grid elements with only a small clearance.

30. Use of Ammeter or Voltmeter.—Since the discoloration of the bulb makes it hard to determine the brightness of the filament, it is good practice to set the filament rheostat by means of a filament voltmeter or ammeter. This will indicate when the tube is being burned at the proper operating conditions. It is preferable to mount the tube in a vertical position, as the filament is not quite so apt to become shorted with the grid when in this position. Shorting of the filament and grid, and noise from the vibration of the filament, may be reduced to a minimum by mounting the tube socket on a cushion support. A 10- or 25-watt tungsten lamp with a voltage rating close to 110 volts may be connected in series in the negative *B*-battery lead, especially when a set has just been assembled. If the *B* battery should happen to be connected across the tube filament the lamp will light up but the filament of the tube will not burn out, as the current is limited by the lamp. After it has been ascertained that the connections are correct, the lamp may be removed from the circuit and the wires joined together to close the circuit.

31. UV-201-A Tube Used as Detector.—The UV-201-A radio tube has a straight-line grid voltage-plate current characteristic curve over a large part of its useful operating range. To secure rectifying action, it is necessary to insert a grid condenser and grid leak in the grid circuit as close as possible to the tube. It is usually possible to secure best results with the grid return connected to the positive filament lead. The grid condenser may be fixed or variable, although very little advantage is generally obtained by using the variable type. The grid condenser should have a capacity close to .00025 microfarad, although values as large as .0005 should work satisfactorily. A grid leak of from two to four megohms will be best for ordinary work with fairly strong signals. Greater sensitivity for weak signals is often secured by a grid leak with a resistance of from four to nine megohms. Unless very reliable in operation it is not good practice to use a variable grid leak.

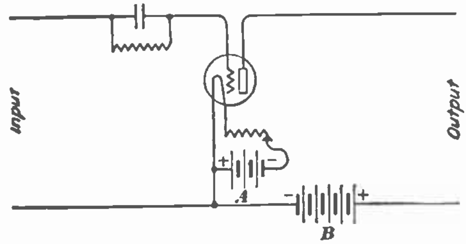


Fig. 8

The circuit connections for a UV-201-A tube connected as a detector tube are shown by Fig. 8. The main feature to notice is that the grid-return connection is made with a positive terminal of the *A* battery. The two leads to the left connect with the tuning apparatus. The plate lead to the right connects with a variometer or whatever device is used to secure regeneration in the set. The plate circuit also includes the output to the telephone receivers or to the transformer feeding into the next tube, and the *B* battery. The *B* battery should have a potential of about 40 volts and its value is not critical, considerably lower or higher values being permissible. The filament voltage is not nearly so critical as with some other types of tubes, although fine adjustments are often desirable when tuning a set to receive faint signals.

32. UV-201-A Tube Used as Amplifier.—The straight-line characteristic curve of the UV-201-A radio tube makes it operate exceptionally well as an amplifier of signals of any frequency. Not only does this tube have a straight-line characteristic curve, but it is relatively steep. This means that the plate-current change is larger per unit of grid-potential change than with most other types of radio tubes. This feature is one of the fundamental requirements of a good amplifier, and makes this tube especially adapted to such use. The large electron emission produced by the thoriated filament is also a factor in making this a good amplifier tube. While the filament energy is not so low as some tubes require, it has a very long useful life and will handle a large amount of energy with minimum distortion.

When the tube is used as an audio-frequency amplifier, it is important that a negative voltage be applied to the grid circuit. This negative bias will tend to give maximum energy amplification with minimum distortion, owing to the fact that operation is over a better part of the tube's characteristic curve. The negative grid bias also decreases the plate current and, therefore, increases the life of the *B* Battery. This is especially important when several tubes are used with a rather high plate voltage. A convenient way to secure a small grid bias is to connect the filament rheostat in the negative *A*-battery lead, and then connect the grid-return lead to the negative battery terminal. By this means, the potential drop in the rheostat will act as a bias of that amount on the grid circuit. When the tube is operated from a 6-volt storage battery, the drop in the rheostat will be about 1 volt, which will be about right with close to 40 volts applied to the plate.

For plate potentials much above 40 volts, a negative grid biasing, or *C* battery, is almost a necessity for best results. The connections of an amplifier tube so arranged as to use the voltage drop in the rheostat and a *C* battery, are shown in Fig. 9.

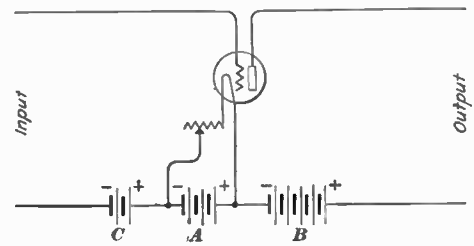


FIG. 9

Table I gives approximate values of grid bias to use with various plate potentials. These values are not critical, and others may also be tried. These may be used in addition to the bias obtained by the rheostat voltage drop.

Since there is no appreciable current drain from the *C* battery, it may be made of compact flash-light cells. Good cells out of a rejected *B* battery will also often give good service as a grid bias.

33. The UV-201-A tube has rather large capacity effects between the elements of the tube. These capacities act like condensers, and, besides producing undesirable losses, are apt to cause the tube and its connected circuits to oscillate when used as a radio-frequency amplifier. If the tube oscillates, it is prevented from amplifying the signals properly. One of the convenient ways of preventing oscillation is to connect the grid-return wire to the slider of a potentiometer across the *A* battery. Enough positive bias is then applied to the grid to prevent oscillations, although such bias introduces considerable loss and distortion into the circuit. It is preferable to balance the tube and circuit-coupling effects, and then use a *C* battery

TABLE I

GRID VOLTAGES FOR UV-201-A TUBE

Plate Voltage	Grid Bias
40	.5–1.5
60	1.5–3.0
80	3.0–4.5
100	4.5–6.0
120	6.0–9.0

to bias the grid of the tube. The positive grid bias is very undesirable, as it causes a heavy drain on the *B* battery, and tends to have an injurious effect on the emission.

UV-199 TUBE

34. Construction and Characteristics of UV-199 Tube. Another tube that uses a thoriated tungsten filament is known as the UV-199 radio receiving tube. This tube or tubes similar in most respects, has been marketed by other manufacturers, as the C-299, and O. T. 9. The UV-199 tube has a very small filament, and is so designed as to give a satisfactory emission with a filament current of about .06 ampere. In the tube as normally constructed,3 volts applied across the filament will send the rated current through the filament, and heat it to the proper operating temperature. The filaments of these tubes are primarily designed for operation with No. 6 dry cells as the current supply, or *A* battery. With three tubes operated from one set of batteries, economical battery life will be secured, probably in excess of 100 hours. The battery life is considerably extended if only two tubes are used, while a very long useful battery life will be obtained if only one tube is operated.

Since new dry cells give about 1.5 volts, two such cells in series would operate the UV-199 tube. However, the voltage of the usual dry cell drops rapidly, but its useful life is not over until this voltage is about 1 volt. It is, therefore, advantageous to connect 3 dry cells in series, and to use up the potential in excess of the rated value by a series resistance or filament rheostat. With one tube in operation it is best to use a 30-ohm rheostat to cut the voltage to its proper value. A 20-ohm rheostat will suffice with two tubes in parallel, and a 10-ohm rheostat will be sufficient with three tubes in operation. It is generally best, however, to use a 30-ohm rheostat, as this will give ample control under ordinary conditions. The carbon-pressure rheostats work well in such service, and are generally capable of giving uniformly fine variations of adjustment. The UV-199 tubes are enough alike in filament characteristics so that two or three, or even more, may all have their filament voltage and current adjustment controlled by one rheostat common to all. A separate rheostat to control the filament supply to the detector tube is often useful as an aid in tuning the set to weak signals. It is essential that an extra series resistance be placed in the filament circuit to limit the current to a safe value if UV-199 tubes are operated from a storage battery or placed in a set that is equipped only with low-resistance rheostats, such as those of the 6-ohm type.

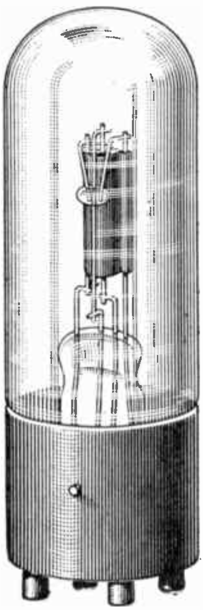


FIG. 10

35. The UV-199 radio receiving tube is usually mounted in a fairly small bulb, and has a bakelite base of about the same diameter. A special arrangement of base pins or contact pins is employed, the better to adapt it to radio-frequency amplification work by placing the grid and plate leads as far as possible from each other, thereby reducing the internal capacity of the tube. The special base requires a special socket for mounting this tube, a feature that tends to prevent placing this tube in a socket with a high-filament voltage supply. Several types of adapters are available which make it possible to use the UV-199 tube in sockets of other types. Such adapters are apt to produce very bad losses, and are not always desirable. A small pin in the side of the base guides the tube into its proper alinement, and locks it in position in the socket or adapter.

36. The UV-199 radio receiving tube is shown in Fig. 10. The only element visible is the plate, although discoloration of the bulb often renders this element invisible. The filament is in the form of a fine straight wire supported at either end by fairly heavy support wires. The filament forms a sort of axis to the surrounding grid, which has a cylindrical shape. The plate is also cylindrical and just outside the grid element.

The elements all have small dimensions, and very small clearances, in order to secure proper operating characteristics. All the elements are securely mounted in their proper relative positions by heavy wires that pass into a part of the glass stem. Four of the support wires are extended through the glass stem and connected with the four pins in the bottom of the base.

As has been mentioned, the UV-199 tube has a very small thoriated filament. As an example of its minute dimensions it is well to note that the filament diameter is close to .6 mil or .0006 inch, a value that is approximately one-fourth that of a human hair. In spite of its small size the filament is quite rugged, and if handled with reasonable care will give a long useful life. Care in handling is also essential to prevent the elements from being short-circuited, which would render the tube inoperative.

37. It is good practice to use a voltmeter to indicate when the proper rated voltage is applied across the filament of the UV-199 tube. There is a tendency to apply an excess voltage to the plate, as such voltage apparently causes an increase in the output of the tube. This practice, if continued, will use up the available electrons faster than they are renewed, and will cause the tube to gradually become inoperative. If a voltage considerably in excess of the rated value is applied to the filament the tube will rapidly lose its emission and become inoperative. A sufficiently high voltage, such as that of the *B* battery, will burn out the filament instantly. The loss of emission, if caused by a high filament voltage, may generally be restored by lighting the filament at its rated voltage, with the plate voltage, or *B* battery, disconnected. The time required to restore proper conditions to the tube will depend on the severity of the mistreatment, and the length of time it was applied.

The filament will also cease to function when the end of its useful life is reached. This is usually manifested by a rather pronounced drop in emission after the tube has been used for a considerable time. It is generally indicated by a tube that requires a filament voltage somewhat above normal to cause it to operate properly. A filament voltage and current less than normal will greatly prolong the useful life of the tube and should be used whenever possible.

The filament in the UV-199 tube, like other thoriated filaments, is injured if gas gets into the tube or if much gas is left during manufacture. A special treatment is applied to the tube during manufacture to remove the last traces of gas remaining in the tube. This process often discolors the bulb to a considerable extent, but this does not affect the operation of the tube as a whole.

38. When the filament is heated, it expands and may tend to bow out toward the grid. The filament may even become short-circuited with the grid if the rated filament voltage is exceeded. Mounting the tube in a horizontal position tends to aggravate the tendency to short-circuit. It is, therefore, considered good practice to mount the tube in a vertical position. If the tube tends to be noisy or to respond to jars, it is well to mount the socket on a cushion support of some sort that will absorb the vibrations. The detector tube is especially bothersome in this respect, as its noises or vibrations are amplified by the succeeding tubes. Interchanging the tubes will frequently minimize the disturbance from this source.

Some experimental work may be best performed with the plate voltage connected. Since the potential of the *B* battery would cause the filament to burn out if unintentionally applied to it, a 10-watt lamp is sometimes connected in series in the *B*-battery circuit. The lamp should have a rating of about 110 volts, and have a 10-watt tungsten filament. Normally, this would not produce an appreciable loss of energy, but would automatically introduce a rather high resistance into the circuit if by chance the tube filament should get connected with the plate voltage. This is due to the fact that the resistance of the lamp filament increases many times when it becomes lighted, which would happen. The lighting of the lamp is also an indication that something is wrong with the circuit.

39. UV-199 Tube Used as Detector or Amplifier.—The UV-199 tube has a characteristic curve that is practically a straight line over a large range of grid voltages. Also, it has no appreciable gas, so it is necessary to connect a grid condenser and grid leak in the grid circuit to secure best rectifying or detector action. The grid return will generally cause the tube used as a detector to give best results when this grid return is connected to the positive filament lead. This feature is shown in Fig. 11, where the grid lead includes the grid condenser *a* and the grid leak *b*. The grid condenser *a* should have a capacity close to .00025 microfarad. For average work, the grid-leak resistance may be from 2 to 5 megohms, while one of 5 to 9 megohms will be more satisfactory when receiving weak signals. A variable grid condenser or grid leak usually does not warrant the added complications of circuit and tuning. The grid-return lead connects with the positive filament lead, which in turn is connected with the positive terminal of the *A* battery. The input leads connect at the left with whatever type of tuning device is desired.

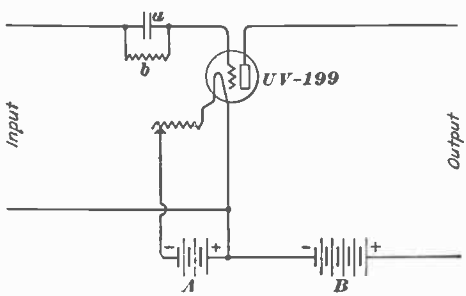


Fig. 11

The filament voltage is not especially critical, but an individual rheostat capable of giving fine variations is very useful. The *B*-battery voltage is likewise not critical and about 40 volts will give uniformly good results. A potential of 60 volts on the plate will generally give somewhat stronger signals, but the drain on the *B* battery is apt to be excessive and the emission of the filament injured. The other devices in the output of the plate circuit are not shown in the illustration, as they vary for different types of sets.

40. The inherent characteristics of the UV-199 radio tube make it function very well as an amplifier of both radio- and audio-frequency currents. This tube has a straight-line grid voltage-plate current characteristic, which means that it will amplify with very little distortion over a considerable range of signal strength. Although the filament energy is small, this tube gives a very good electron emission. When properly connected, the UV-199 tube is capable of giving a strong enough plate-current variation to operate a loud speaker. The amplifying power of individual tubes is very satisfactory, so that an excessive number of stages of amplification is not necessary.

A negative grid bias should be applied to the grid of the UV-199 tube when it is operated as an audio-frequency amplifier. This causes the tube to function over a good part of its characteristic curve, and to amplify with minimum distortion. A grid bias also decreases the plate-current drain on the *B* battery, and prolongs the life of the battery. This feature is of importance when several amplifier tubes are used, and with the higher plate voltages. The *C* battery also helps to prolong the useful life of the tube, and is an important factor in tube life with a high plate voltage. A small grid bias may be secured by utilizing the potential drop in the filament rheostat. This is best secured by placing the filament-control rheostat in the negative battery lead and connecting the grid return between the rheostat and negative battery terminal. This is shown in Fig. 12 with the grid-return lead connected so as to utilize the voltage drop in the rheostat. The grid bias secured by this means will usually prove sufficient for plate voltages not much in excess of 40 to 44 volts.

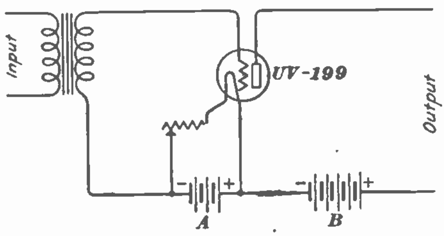


FIG. 12

41. For plate potentials much above 40 volts it is well to use a *C* battery to give the proper negative bias to the grid. Approximate values of grid-bias voltages are the same as those given for the UV-201-A tube in Table I. These values are not critical, and higher and lower voltages should be tried if these do not give the desired results. These values may be applied to the grid in addition to that furnished by the filament-rheostat drop. One method of connecting a *C* battery in the grid circuit of amplifier tubes is shown in Fig. 13. Here one *C* battery is used for two amplifier tubes. The input circuit of this two-stage audio-frequency amplifier may be connected directly in the output circuit of Fig. 11. If no *C* battery were used, the lead from the secondary of the transformer *a*, Fig. 13, which now is shown connected to the *C* battery, would be connected to the negative terminal of the *A* battery. One rheostat is used to regulate the filament current for both tubes.

When the UV-199 tube is used in a radio-frequency amplifier, it is usual to connect the grid return, or all of the grid returns,

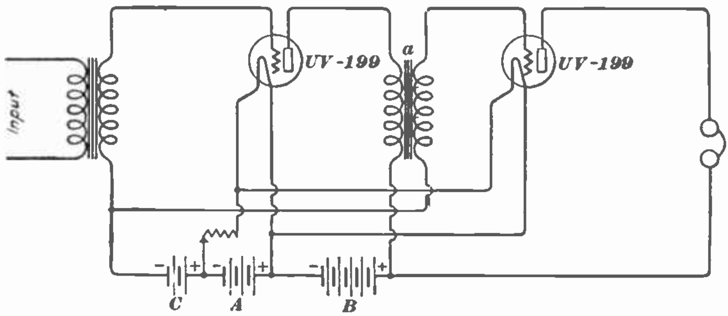


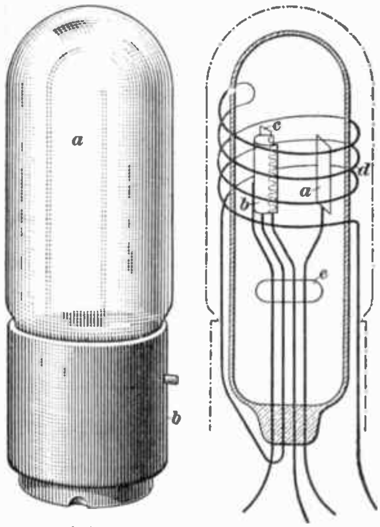
FIG. 13

if more than one tube is used, to the slider of a potentiometer that will give a positive bias to the grid. The tendency of this tube to oscillate is not so great as with other tubes, yet when it is connected in coupled circuits that are more or less tuned to each other, the tube will oscillate. About the most convenient way to prevent oscillations is to employ the positive grid bias just mentioned. The positive grid bias prevents oscillation by introducing losses into the input circuit. This bias is usually secured by connecting a potentiometer across the *A* battery and attaching the grid-return lead to the slider of the potentiometer. The slider is then moved over its range of values to a position that just prevents the set from oscillating.

If the radio-frequency circuit can be prevented from oscillating by other means, such as balancing the circuits, it is good practice to use a negative grid bias to secure best results.

SODION DETECTOR TUBE

42. Construction of Sodion Tube.—The Sodion S-13 detector tube differs from the tubes heretofore described not only in its construction but also in its operating characteristics. The external appearance of the sodion tube is represented in Fig. 14 (*a*). There is an inner and an outer glass tube. The internal construction of the inner tube is shown diagrammatically in view (*b*). The anode *a* corresponds with the plate of other vacuum tubes. The collector *b* is **U** shaped, and within it is the filament *c*. In series with the filament, is a coil *d* consisting of a few turns of resistance wire, which, when the filament circuit is completed, supplies the necessary heat for the proper operation of the tube.



(a) (b)
FIG. 14

The coil *d* is non-inductively wound and it is placed between the outside of the inner glass tube and the inside of the outside glass tube. The supporting wires for the elements of the sodion tube are held in position by a glass bead *e*. The inner tube and its elements are placed in an outside glass bulb *a*, view (*a*), and as much as possible of the air is removed from the inner tube. A small quantity of sodium is introduced into the tube, which is then sealed, and fastened to the base *b* with the terminals of the elements connected to the terminals in the base.

43. Operation of Sodion Tube.—The operation of the sodion tube may best be explained by considering the tube in action in a receiving circuit as indicated in Fig. 15. In addition to the tube consisting of the anode *a*, the coil *b* (conveniently shown above the elements instead of surrounding them), the filament *c*, and the collector *d*, other devices are provided including the 40-ohm potentiometer *e*, the 100-ohm resistance *f*, and the 15-ohm rheostat *g*. The usual *A* and *B* batteries are also required. The tuning circuit consists of a tuned radio-frequency transformer *h*, the primary of which may be adjusted by varying both the inductance and capacity, while the secondary is tuned by means of a shunt variable condenser. The coupling between the primary and secondary coils is variable.

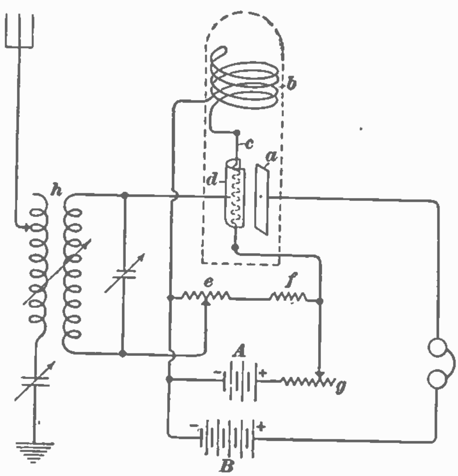


FIG. 15

As soon as the battery circuits are closed, an electron discharge takes place from the filament *c*. The freed electrons are more strongly attracted by the anode *a*, but quite a large number of them are brought toward the collector *d*, which normally has a negative potential applied to it. The anode circuit aids the liberated electrons; in the collector circuit the liberated electrons are obliged to travel against the negative collector potential.

So far the action is quite simple. As soon as the alkali vapor due to the presence of sodium becomes active, the electrons in their travel from the filament to the anode collide with atoms of the alkali metal, the result being an ionization of the gas. The positive ions will move in the dense electronic field near the filament and partly neutralize the space charge.

This will increase the electron flow in the collector circuit, which will react on the anode circuit, causing there a still greater flow of electrons and more collisions with the alkali atoms. This action continues until a balance is reached, which depends on the anode and collector fields, the filament temperature, and the vapor pressure.

44. A high-frequency incoming signal in the antenna circuit will induce high-frequency alternating voltages in the collector circuit, Fig. 15. When the voltage on the collector is such as to oppose the existing negative bias, more electrons will flow to the collector, and also to the anode. A reversal in the collector voltage so as to aid the negative bias thereon, will result in the repulsion of electrons from the collector. This causes a large drop in both the anode and collector currents, in that the initial cause of ionization has been removed. A relatively long time is then required for the tube to balance itself. The next positive half-cycle on the collector will have very little effect on the action of the tube, but the following negative half-cycle will again unbalance the tube. Thus the positive half-cycles have little effect on the normal action of the tube, and the negative half-cycles produce a very large change in the anode current. This effect is the basis of a detector tube, and for this reason the sodion tube is so effective in radio receiving circuits as a detector.

45. The sodion tube has a specially treated filament that requires but $\frac{1}{4}$ ampere for proper emission at a pressure of approximately 3.4 volts. The plate, or anode, circuit requires a $22\frac{1}{2}$-volt battery. This tube will not oscillate, hence no interference will be produced by sets in which this tube is used alone. The clearness of the signals compares favorably with that obtained with crystal detectors and the strength of the signals is practically the same as with a regenerative receiver.

The sodion tube may be used in circuits employing radio-frequency amplification, but its battery connections should be the same as in Fig. 15. Also, one or more stages of audio-frequency amplification may be added to sets using a sodion tube as a detector.

RECEIVING-TUBE CHARACTERISTICS

SUMMARY

46. Many of the important characteristics of the more common types of radio receiving tubes have been given along with the description of those types. Some of those values are summarized in Tables II, III, and IV, which give this information in a handy form. Additional characteristic values in the tables give information to be considered when purchasing or building a receiving set. Most of the numerical values given represent averages of large numbers of tubes. In some cases, however, the minimum or maximum allowable limits, or the recommended values are given. The manufacturers occasionally make changes or improvements in design that may alter the averages from the values given here, but such changes are generally not objectionable, as they tend toward better tubes.

47. The filament-circuit data in Table II give information relative to the recommendations as to the rated conditions under which the tube should be operated. The over-all dimensions are of interest in determining the amount of space that will be required by the tube or tubes, especially, in a compact set. The grid-condenser and grid-leak values as well as the plate voltages are values that are recommended as best for average operating conditions. It is more common practice to operate the UV-200 tube without a grid leak, but, if one is used, the range given in the table should be followed. With strong signals and bad static the UV-200 tube operates best when a lower resistance grid leak is used. Similarly, the grid leak should have a relatively high resistance when receiving faint signals and with little static. The characteristics of detector tubes are given in Table II, of amplifier tubes in Table III, and of Western Electric Radio Tubes in Table IV. The values given in these tables are recommended as average values, and individual cases may be considerably different.

TABLE II

DETECTOR TUBES

Tube Type	Filament Circuit Data: Battery Source Voltage	Filament Circuit Data: Filament Terminal Voltage	Filament Circuit Data: Filament Current, in Amperes	Dimensions Maximum Over-all: Length, in Inches	Dimensions Maximum Over-all: Diameter, in Inches	Detector Data: Grid Condenser, Microfarads	Detector Data: Grid Leak, Megohms	Detector Data: Plate Voltage Minimum	Detector Data: Plate Voltage Maximum
WD-11	1.5	1.1	.25	3.25	1.25	.00025	2 to 3	20	45
UV-199	4.5	3.0	.06	3.5	1.0	.00025	2 to 9	20	45
UV-200	6.0	5.0	1.0	4.31	1.75	.00050	.5 to 2	16	23
UV-201	6.0	5.0	1.0	4.31	1.75	.00025	2 to 3	20	45
UV-201-A	6.0	5.0	.25	4.31	1.75	.00025	2 to 9	20	45

TABLE III

AMPLIFIER TUBES

Tube Type	Amplification Factor K	Negative Grid Voltages for Various Plate Potentials: 40	60	80	100	40 Volts Plate, 0 Volts Grid: Plate Impedance, in Ohms	Mutual Conductance, Micromhos	Plate Current, Milliamperes	80 Volts Plate, −4.5 Volts Grid: Plate Impedance, in Ohms	Mutual Conductance, Micromhos	Plate Current, Milliamperes
WD-11 / WD-12	6.5	1.	3.0	4.5	6.0	19,000	340	1.2	17,300	375	1.8
UV-199	6.25	1.0	3.0	4.5	6.0	18,500	340	1.2	16,500	380	1.7
UV-201	6.0	.0	1.5	3.0	4.5	20,000	300	1.2	17,300	350	1.8
UV-201-A	8.0	1.0	3.0	4.5	6.0	16,500	485	1.3	13,200	600	1.6

TABLE IV

WESTERN ELECTRIC RADIO TUBES

Tube Type	Main Uses	Filament		Plate Volts	Amplification Factor	Normal Plate Impedance
		Volts	Amperes			
E..................	A, O, and M	7.0	1.35	350	7.	4,000
J..................	D and A	2.5	1.2	40	6.	15,000
L..................	R, A, and O	6.0	1.25	125	5.	5,000
N..................	A, D, and O	1.5	.25	60	5.5	25,000
O..................	IA	6.0	1.25	100	2.5	2,000
V..................	VA and R	3.0	1.25	125	30.	50,000
216-A..........	A	6.0	1.1	100	6.	8,000

The *conductance* of a body is the reciprocal of the resistance of the body. The units of conductance are the mho and certain of its multiples and the units of resistance are the ohm and certain of its multiples. *Mutual conductance* is obtained by dividing the amplification factor by the plate impedance, as explained later. The letters in column 2 of Table IV have the following significance: A, amplifier; D, detector; IA, current amplifier; M, modulator; O, oscillator; R, repeater; and VA. voltage amplifier.

CHARACTERISTIC CURVES

48. The properties of a tube may be shown by curves that cover most of the operating range of conditions. Such curves are often very useful in determining certain of the characteristics where elaborate test methods are not available. A set of these curves is given in Fig. 16, where the curve *a* represents the plate current for various values of grid voltage obtained while the plate and filament potentials are maintained constant. The plate current becomes zero at the lower left end of curve *a*; that is, there is no plate current or flow of electrons to the plate, as it is stopped by the negative grid voltage. As the grid voltage becomes less negative, and finally positive, the plate current increases over a path that is a straight line for a considerable part of its range. At a relatively high positive value of the grid potential, the plate-current increase becomes less pronounced and finally reaches a maximum. This is indicated by the bending over of the curve at its upper right end, and represents the saturation current under those particular conditions. With still higher positive grid voltage the grid may, under the proper conditions, take current enough to cause the plate current actually to diminish in value.

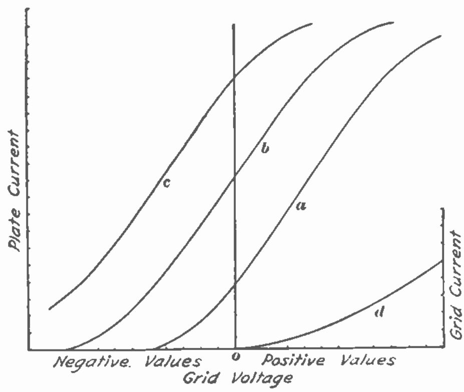


FIG. 16

49. The curves *b* and *c*, Fig. 16, indicate the variations of plate current under similar test conditions, but with higher values of plate voltage, the curve *c* having a plate potential somewhat higher than the curve *b*. It should be noted that the curves *b* and *c* have about the same general shape as does the curve *a*, the main difference being that the higher plate voltage has moved the corresponding characteristic curves bodily to the left. Extreme plate voltages below and above the values required to produce these curves will produce rather irregular curves that may or may not resemble those obtained over the usual operating range. All of these curves preserve a constant filament temperature and other conditions are constant during any one test.

50. The curve *d*, Fig. 16, represents the grid-current values observed while taking the data for the curve *a*. However, as the grid current is only slightly less for the higher values of plate voltage used in determining curves *b* and *c*, separate grid-current curves are not drawn for these conditions. The grid current is zero with the negative grid potentials, and does not start until positive grid voltages are applied. As the grid voltage is made more positive the grid current increases in a non-uniform manner. The grid current, over the range shown, is much smaller than the accompanying plate current; for instance, each division of the grid-current scale might represent a current one-tenth as large as that indicated by the divisions of the plate-current scale.

TEST CIRCUIT

51. A convenient arrangement for securing the data to plot the characteristic curves of a tube is shown in Fig. 17. The tube under test is shown at *a* with a filament rheostat at *b*. This rheostat should be set so that the *A* battery impresses exactly the rated voltage on the filament of the tube. This filament voltage may be read by the voltmeter *c* at the beginning of the test, and should not need rechecking if the *A* battery is of a reasonable capacity. The voltmeter *c* is installed so that the switch *d* will connect it in the circuit to read either the grid or the plate potential. The plate current is read by a milliammeter *e* connected in the plate circuit. A tap on the *B* battery will permit of various plate potentials for the tests. The microammeter *f* will prove useful if the grid current readings are to be taken. A double-pole double-throw switch at *g* is a convenience in applying either a

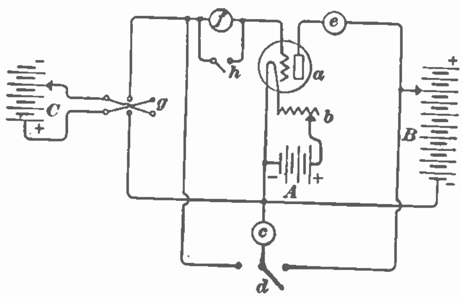


FIG. 17

positive or a negative potential from the *C* battery on to the grid. A short-circuiting switch at *h* protects the meter *f* from large grid currents taken with some *C*-battery adjustments.

The voltmeter *c* should have a scale range capable of reading 100 volts, although one with a somewhat higher range will serve the purpose. If the voltmeter has a low-range scale also, say one with a full scale reading of 10 volts, this scale will be more accurate for *A*- and *C*-battery potential readings than will the low-voltage portion of the high voltage scale. If only a low-range voltmeter is available, it will be necessary to read the potential of various sections of the *B* battery, and add these values to secure the plate-voltage reading. The plate milliammeter should have a range of about ten milliamperes, although one with a five-milliampere range will give values over a range sufficiently large to be satisfactory for most purposes. If sensitive to small currents, the same instrument may be used to read the grid current, although this is seldom possible. A very sensitive meter is preferable for reading the grid current, if such values are desired. One with a full-scale reading of say, 100 or 200 microamperes will cover the range necessary for most of the commercial types of radio tubes.

OTHER CHARACTERISTIC CURVES

52. Characteristic curves of the tube under test may be taken in different ways. The plate-current variations with grid-voltage changes taken with various fixed plate and filament voltages show many important characteristics of a tube. For such curves, the filament voltage should be set at the value recommended by the manufacturer. This would be done by connecting the voltmeter *c*, Fig. 17, or any other convenient voltmeter, across the filament terminals (exclusive of the rheostat) and adjusting the rheostat *b*. The voltmeter *c* should now be connected across the *B* battery and the plate voltage set at any desired value within reasonable limits. The voltmeter *c* may now be connected across the *C* battery, and left there for convenience in making grid-voltage adjustments. Switch *h* should be left closed for this particular test.

A set of curves such as those shown by curves *A*, *B*, *C*, *D*, *E*, *F*, *G*, and *H*, in Fig. 18 may now be obtained. Take curve *C* for an example, which is fairly typical of the group giving values of a tube with rather good characteristics that are somewhat similar to those of the UV-201-A tube. For curve *C* the plate voltage would be set at 60 volts and left at that

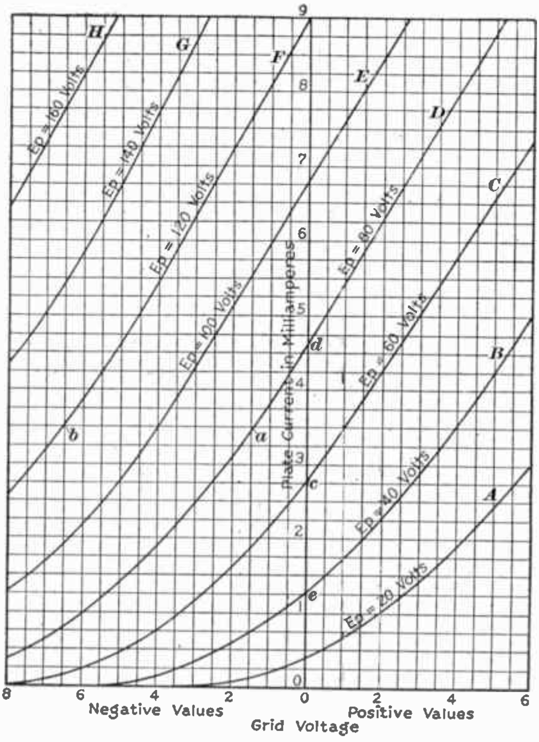


FIG. 18

value throughout the test. The *C*, or grid-bias, battery would be adjusted to read 8 volts with switch *g*, Fig. 17, thrown to the proper position to make the grid negative. With this condition, the plate current is very close to zero, as read by the milliammeter at *e*. As the grid bias is reduced toward zero, the decreased space-charge effect permits more electrons to pass from the filament to the plate, which produces a larger plate current. This is shown on curve C, Fig. 18, by the larger plate-current readings given with the grid-voltage reading near the center of the range. As positive grid voltages are applied, the plate current reaches even greater values, as evidenced by the higher current values toward the right end of curve C. The other similar curves would be secured by the same procedure of grid-voltage variation with other values of fixed plate potential. It will be necessary to reverse voltmeter c, Fig. 17, whenever the grid voltage is reversed during the tests.

53. The curves of Fig. 18 are of value in determining the proper grid-bias voltage to use with any particular plate voltage. As is seen by an inspection of the curves, the plate current becomes excessively high with the higher plate voltages, say 80 volts and above, when there is no grid bias; that is, when the grid voltage is zero. A considerable C battery or grid bias should be applied to amplifier tubes with high plate voltages, chiefly to limit the plate current. The plate current is smaller with the lower plate voltages, but amplifier action, as has been explained, does not take place over such a straight portion of the curve.

The amplification factor, K, *Mu*, or μ, as it is variously called, may be obtained from data given by the characteristic curves. Note the grid and plate voltage necessary to give any convenient value of plate current, as that represented at point a, Fig. 18. Determine the grid voltage that gives the same plate-current reading with a higher plate voltage, such as is indicated by point b. The plate-potential change is $120 - 80 = 40$ volts. The corresponding grid voltage change is from -6.5 to -1.5 volt or a total change of 5 volts. The amplification factor is the plate-voltage change divided by the grid-voltage change with a constant plate current or $\frac{40}{5} = 8$. This value is practically constant for various grid and plate voltages, except over the lower plate-current values.

54. The filament-to-plate impedance is another property of the tube that may be obtained from the characteristic curves. This is made up chiefly of the resistance offered to the passage of the plate current, as electrons, between the filament and the plate elements. The plate impedance may be determined by dividing any plate-voltage change by the corresponding plate-current change. For the plate impedance with 60 volts on the plate and with no grid bias, as indicated at point *c*, Fig. 18, it will be desirable to take the plate-voltage change between 40 and 80 volts and note the corresponding plate-current change. Thus, by taking a range of variation of 20 volts on each side of the desired point, the required value may be obtained. The plate current at point *d* with 80 volts is 4.6 milliamperes, and 1.25 milliamperes at point *e* with 40 volts on the plate. The 40-volt change, therefore, produces a plate-current change of $4.6-1.25=3.35$ milliamperes, or .00335 ampere with these conditions. The plate impedance is $\frac{40}{.00335}$ $=12{,}000$ ohms, nearly. If the plate impedance is taken at other grid- and plate-voltage conditions, considerably different values will be secured. For this reason the actual conditions should be specified whenever plate-impedance values are given.

A factor that is of extreme usefulness in specifying the amplifying power of a tube is the mutual conductance. It is more accurate than the amplifying factor alone, since the mutual conductance gives more specifically a measure of the control exercised by the grid over the plate current. The mutual conductance is the result obtained by multiplying the amplification factor by 1,000,000 and dividing by the plate impedance. This gives the mutual conductance in micromhos. The values which have just been used would give a mutual conductance of $\frac{8\times 1{,}000{,}000}{12{,}000}=670$ micromhos, approximately.

POWER TUBES

GENERAL CLASSIFICATION

55. The electron tubes most commonly met with in radio are those used in radio receiving sets. This includes several types designed to meet particular requirements of that field. Electron tubes capable of handling considerable amounts of power are widely used in radio transmitting stations, and in many lines of commercial application.

The small tubes designated particularly as for use in radio receiving sets will serve as a means of radio communication over short distances when properly handled. This means that, for best results, the tube should be connected in a suitable circuit; and a relatively high plate voltage is an added advantage. With care two or more tubes may be used in parallel, although it is generally preferable to employ a single large tube rather than several of a smaller size.

56. Power tubes are made in various sizes, each being rated according to the power that can be dissipated by the plate element. With the usual circuit arrangement, the power output from the plate circuit does not exceed that dissipated by the plate element. Usually the largest output is secured when the output impedance, or the external plate-circuit impedance, equals the plate impedance of the tube. This is due to the operating characteristics of the tube, and is seldom realized in practice. Since the amount of power that the tube can dissipate is a real limit on the tube's performance, it forms a convenient means of rating power tubes. The rated energy may be exceeded to some extent, but with considerable risk. An output less than the rated value is conducive to long filament and tube life with a minimum of trouble.

One of the chief requirements in selecting a power tube is the matter of power output. Most types will operate quite well in the more conventional types of oscillator, amplifier, and transmitter circuits. Examples of such wiring diagrams are given in other Sections, and are not reproduced here.

5-WATT POWER TUBE

57. The 5-watt power tube most commonly found on the market in the United States is listed by one manufacturer as the UV-202 and by another as the C-302 tube. Both styles are practically identical, especially in so far as the electrical properties are concerned. The 5-watt tube is ordinarily equipped with the standard bayonet base with the four contact pins. The bulb is somewhat larger than is usual with receiving tubes using this type of base.

The plate of the 5-watt tube is of a flattened oval construction, and of a size able to dissipate 5 watts of electrical energy, which it receives from the electron flow. The grid is mounted just inside the plate and has the same general outline. The filament is fairly rugged, and is mounted in the form of an inverted **V**, inside the grid element.

The filament terminal voltage is rated at 7.5 volts, which requires an 8- or 10-volt A-battery supply. A 1-ohm rheostat will give satisfactory filament control. The filament current under the above conditions is close to 2.35 amperes. A normal plate potential of 350 volts is recommended, although lower and even higher values may be used. It is always desirable to bias the grid so as to limit the plate current to reasonable values. At 350 volts on the plate and with no grid bias, the plate current is close to 50 milliamperes. This plate current is reduced to a value close to 10 milliamperes by a grid bias of 30 volts. The average amplification factor is 7.5, while the plate impedance is close to 5,000 ohms with 350 volts on the plate, and 0 volts on the grid.

58. The filament and plate circuits may be economically operated from storage batteries. The tube is designed for use in a transmitting set, and separate tubes may serve as the oscillator and the modulator in a low-power telephone transmitter. In such cases the output may be increased by connecting additional tubes in parallel, all the tubes in any one group operating as a single unit. It is important that all tubes in any one group should operate at exactly the same filament temperature. The filament leads should be short and so arranged that there is an equal voltage drop in the leads from the battery to each tube. A UV-201-A tube may be used as a speech amplifier feeding into the UV-202 tube, which acts as a modulator. If the tube is operated by alternating current, it is necessary to have access to the center of the filament-transformer output winding, as a connection point for the grid- and plate-return leads. When there are several tubes in the oscillator of a radio-telephone transmitting set, best results will be secured with an equal number of modulator tubes.

The 5-watt tube may be used as an amplifier in the intermediate stages for a large-power telephone transmitting station. In such use it is desirable to operate the tube under such conditions that it will be especially free from any tendency to cause distortion in the amplified signal. Too strong signals should not be used, and the grid bias should be accurately adjusted to the proper value. The filament should be operated at the lowest temperature consistent with satisfactory output. This will give maximum life to the filament, with minimum use of power. This type of tube, as well as most others, is equally applicable in the transmission of telegraph or telephone signals.

50-WATT POWER TUBE

59. The commercial tube next in size to the 5-watt tube has an output rating of 50 watts. This type of tube, as made by various manufacturers in the United States, is commonly listed as the C-303, and the UV-203. When made with the thoriated tungsten filament these numbers have the *A* suffix.

A 50-watt power tube is shown in Fig. 19. The base and bulb have a diameter of 2 inches, and the maximum over-all length is just less than 8 inches. The base is of an extra-large size and has a special arrangement of base pins. The grid and plate pins are mounted diagonally opposite each other so as better to prevent arcing, since rather high voltages are used. The tube should be mounted in a vertical position with the base end down.

The 50-watt power tube is rated to operate with a filament terminal potential of 10 volts. This is best supplied from a 12-volt source suitably controlled with a rheostat. The filament current on the pure tungsten filament tube is rated at 6.5 amperes, while the thoriated filament takes about 3.25 amperes. The rated and recommended plate potential is 1,000 volts. The amplification factor of the older type would average close to 15. The newer tubes with the thoriated filament have a higher average amplification factor; namely, 25, owing to changes in design and the large filament surface area. The plate impedance is approximately 5,000 ohms, with 1,000 volts on the plate and zero volts on the grid, these figures applying to both types. The plate current is about the same for tubes of the two types; namely, about .125 ampere with 1,000 volts on the plate and a zero grid bias.

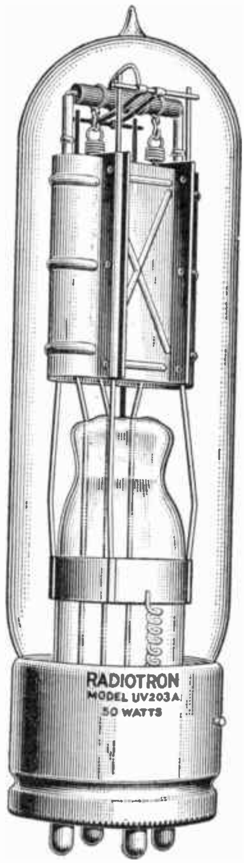


FIG. 19

60. The plate element maintains a fairly high operating temperature when the tube is functioning properly. A safe condition obtains when the plate has a reddish color, but too white an appearance should be guarded against. Since air cooling is relied on, a free circulation of air around the tube is essential. The plate power dissipation should never exceed 100 watts, even for short periods of operation. The plate voltage should be lowered to prevent damage to the tube or auxiliary apparatus in case a wrong connection is accidentally made while trying a new circuit or adjustment. It is interesting to note that the plate is mounted rigidly from a collar clamped securely around a part of the glass framework, a practice that gives good insulation for the high plate voltages.

A 50-watt power tube generally has the filament energized from an alternating-current supply line. When such is done the grid and plate return connections should be made to the center tap on the secondary of the transformer. The filament rheostat should be in the primary lead. The plate-return lead should connect with the positive filament terminal when it is necessary to use direct current to light the filament. The plate voltage is supplied either by a high-voltage direct-current generator or by a rectified alternating current. In the latter case special rectifier tubes are essential, together with a filter coil and condenser combination to smooth out the rectified wave.

61. A 50-watt power tube works well in a medium-power telegraph transmitting set, and is capable of establishing communication over great distances. The properties of different tubes of any one type are enough alike so that two or even more may be operated in parallel for greater output. When the tubes are operated in parallel, small choke coils should be connected in the grid leads to prevent the establishment of very high-frequency oscillating currents. The 50-watt power tubes will also operate very well as oscillators and modulators, and may be connected in any of the reliable radio-telephone transmitter circuits. Circuits suitable for this and other applications of these tubes are given in other Sections.

The 50-watt tube has a rather high amplification factor and a relatively low plate impedance, factors which are of extreme importance in an amplifier tube. These properties, together with its ability to handle large amounts of power without introducing distortion, make it a good amplifier tube for supplying energy to the grid circuit of still larger-powered transmitting tubes. When so used, the tube and its auxiliary circuits must be carefully adjusted to secure the best operating conditions. When used as a modulator or amplifier, the plate current should be limited to less than .075 ampere by a grid bias. A 20-volt negative bias on the grid should accomplish this result. If it does not, this fact is often an indication that the tube is oscillating at some high frequency, possibly above audibility.

62. The 50-watt tube with the thoriated filament has a somewhat longer life than does the pure tungsten-filament tube. The thoriated filament tube is apt to lose its emission if subjected to a heavy overload. Unless the overload is so severe as to liberate a considerable amount of gas, the filament may be revived by burning at the rated filament voltage, with the plate voltage off, for one-half to one hour. The life of the filament is extended by operation at the lowest temperature that is consistent with satisfactory output. A voltmeter connected directly across the filament terminals will indicate the proper conditions. It should be noted that the filament operating temperature is considerably lower with the thoriated filament, and that the method of setting the filament voltage by merely looking at the filament is very unreliable.

250-WATT POWER TUBE

63. A still larger commercial type of power tube is that rated to deliver a continuous output of 250 watts of radio- or audio-frequency energy. This size of tube has the general characteristics of the smaller three-element electron tube, but is constructed of a size capable of handling much more electrical energy. A different style of construction is necessary to protect against breakdown by the high voltages that are necessary between some of the elements.

Most of the 250-watt power tubes manufactured in the United States are listed as model UV-204 or C-304, with the *A* suffix if the filament is made of thoriated tungsten. There is very little difference in the appearance of those with the tungsten filament from those having the thoriated filament. One of the latter type is illustrated in Fig. 20. As may be seen in the illustration, the anode, or plate, lead is taken out of the bulb at the end opposite the grid and filament leads.

Special mounting clips are required which support the tube from both ends. The tube may be mounted either vertically of horizontally. When vertical, the anode, or plate, lead is at the bottom, and when mounted horizontally the plate element should be on edge. Since the bulb becomes quite hot in operation. it should not come in contact with inflammable materials nor be subject to drops of spray of any liquid on the glass. A free circulation of air around the bulb is absolutely necessary to prevent overheating. It is especially important to keep the plate wiring well away from the grid and filament circuit wires, and both the grid and plate wires away from the glass bulb, else breakdown or puncture is likely to occur. In some circuit connections there are likely to be excessively high peak voltages induced between the grid and filament. A $\frac{3}{32}$-inch spark gap between the grid and one of the filament terminals should form part of the tube mounting.

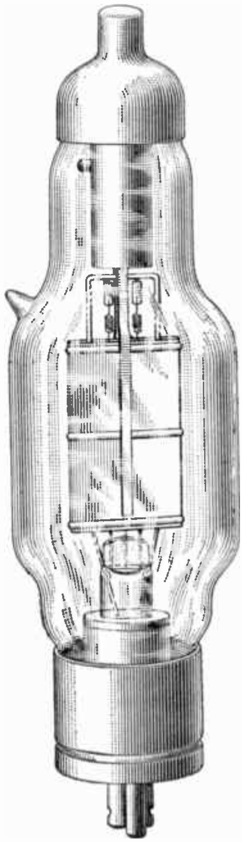


FIG. 20

64. The 250-watt power tubes are rated for filament operation at 11 volts directly across the terminals. The tungsten filament tubes require an average of 14.75 amperes, while only about 3.85 amperes are necessary to heat the thoriated filament to the proper operating temperature. The amplification power is approximately 25 and the plate impedance close to 5,000 ohms for both the pure tungsten and the thoriated filament tubes.

The rated plate potential is 2,000 volts and the plate current is close to .25 ampere with that plate voltage and with no grid bias. The maximum over-all length is about 14½ inches, and the maximum bulb diameter is 4 inches in most cases, although some tubes are manufactured with bulbs having a maximum diameter of 5 inches.

65. The filament of the 250-watt power tube is preferably heated by an alternating-current supply. The secondary coil that heats the filaments should have a center tap or mid-tap to which the grid and plate-return circuits should be connected. The filament rheostat should be placed in the primary lead to the transformer, and should have a resistance sufficiently great to reduce the filament voltage to about ¾ of its rated value. It is frequently possible to operate the tube under this condition with greatly increased life. If it is necessary to use direct current on the filament, the plate return should be connected to the positive filament terminal. The filament rheostat should be placed in the positive lead.

66. The plates of the 250-watt tubes operate at a fairly high temperature, often approaching a white heat for normal output. An efficiency, or ratio of output to input, of 50 per cent. should be possible with proper adjustment of the various circuits. According to the rating the plate-power dissipation should never exceed 300 watts for continuous operation, and a better life will be secured if this is kept to 200 watts. If the tube is overloaded, a fan blast will help keep the plate temperature down, and also tend to prevent arcing or breakdown in the tube. The plate voltage may be supplied from a direct-current generator, or from a rectified alternating-current supply source. In the latter case some type of filter inductances and condensers are necessary to reduce the current pulsations to a minimum, and some such procedure is frequently necessary with the generator supply. When the tube is tried in new circuits or with different arrangements or adjustments, a precautionary measure is to lower the plate voltage below normal until all the connections have been carefully inspected and found to be correct.

67. The grid lead of each tube should have a small choke coil located close to the grid terminal when several tubes are operated in parallel. This will tend to prevent the establishing of very high-frequency currents between the grid and plate circuits of the several tubes. Any resistance units in the grid lead, such as grid leaks, should be non-inductive or nearly so to prevent them from collecting high-frequency currents from other nearby devices, or to prevent them from partially tuning the grid circuit to establish oscillating currents.

68. Although not often so used, the 250-watt power tube makes an excellent amplifier where that amount of output power is desired. The electrical properties of this tube are such that it will operate as an amplifier for signals of any frequency with a minimum of distortion. It is, of course, necessary to have the tube and its auxiliary apparatus correctly adjusted.

The 250-watt tube is primarily designed for operation as an oscillator and modulator for use in radio-transmitting work. It represents a unit, which, under reasonable conditions, will give a good communication range, whether by telephony or by telegraphy. The range may be increased by connecting several such tubes in parallel. A negative grid bias sufficient to limit the plate dissipation of energy to safe values, should be used when employing the tube as a modulator or power amplifier. A bias of about 60 volts provided by a battery source should be ample under normal conditions. If the plate current greatly exceeds its rated value with the grid bias, it is often an indication that the tube is oscillating at some high frequency.

WATER-COOLED HIGH-POWER TUBES

69. Most of the smaller-sized power tubes are designed to operate in a satisfactory manner when the bulb is left to cool merely by exposure to air. This method of cooling is successfully applied to power tubes with ratings up to and including the 250-watt size. Cooling under normal operation is accomplished by air-currents set up by the heat of the bulb. If the tube is overloaded, it may tend to heat the plate and bulb to a dangerous temperature unless forced draft is utilized.

Some air-cooled power tubes have been made with output ratings greater than 250 watts, and have given good results. In general, however, such tubes require excessively large plates and bulbs, and are very subject to heating troubles, on account of the large amount of power that they must dissipate. The more usual practice, in tubes that must handle several kilowatts of power, is to make the plate element a part of the outer container, and to cool the plate with water. This necessitates a vacuum-tight seal, one that will maintain a vacuum on one side, between the glass bulb and the metal plate. This is commonly accomplished by melting the glass to join a thin piece of copper, which forms a sort of fin to the plate proper. The grid lead is often taken out through the side of the glass bulb in order to separate it as much as possible from the filament and plate elements.

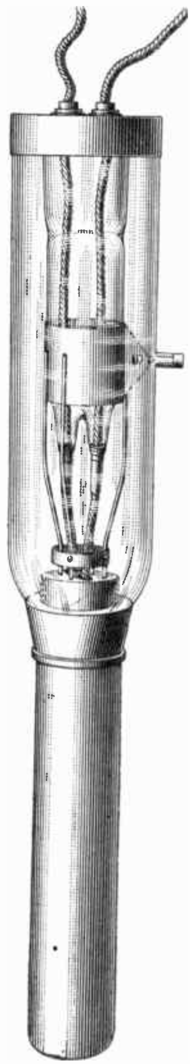


Fig. 21

70. One type of water-cooled power tube, sometimes called the UV-209, is shown in Fig. 21. The plate element is shown at the bottom of the illustration, and forms an air-tight joint with the glass bulb above. The grid element is formed of a tubular or helical winding that fits inside the cylindrical plate. The filament comprises two straight lengths of tungsten wire supported by a small rod between them.

No base is provided ordinarily for the water-cooled power tubes. Connection to the various elements is made by special means to suit the particular case under consideration. Several precautions are essential, however, in installing such special apparatus. The glass-to-metal seal is a weak spot in the tube, although with care it should not cause trouble. Special care should be taken to see that no undue strain is put upon the seal through tension in the leads or through poor mounting. The flexible filament leads carry a very large current, and must be securely attached to the external or supply circuit to prevent excessive heat loss, which would soon destroy the leads.

71. The water-cooled power tube should always be operated, and stored, with the glass-bulb end up. It should not be subjected to excessive vibration. The water-cooling system should be so designed as to provide uniformly steady cooling for the whole surface of the plate element. There should be no air pockets in the cooling surface, as this would let the plate get too hot at that point, with the possibility of ruining the tube. A positive means for preventing operation of the tube must be provided for protection in case the cooling water supply fails. Operation for only a few seconds without cooling water will probably destroy the tube, so this protective device must be absolutely reliable. It is a good plan to make a connection so that the filament current cannot be turned on if there is no water flow.

One of the best methods of cooling is by connection with a small radiator cooled by a fan. A pump should be used to produce positive circulation of the water through the tube chamber. A thermometer is useful in determining the temperature of the cooling water, which should be kept well below the boiling point. Another good method of cooling is by use of the local water supply. Such water, if reasonably pure, has a high enough resistance to prevent undue loss of energy. About two gallons per miuute will serve to keep the plate element cool. A fairly long rubber hose connection, say 20 feet, should be made in the input and output connections, with the hose coiled to form an inductive choke to the passage of stray electric currents. Another method, that is less desirable, is to use some sort of radiator as the actual cooling device, but without a pump to force the water to circulate. In such a case the connection piping must be of large size and short in length to allow of as free circulation of the water as possible.

72. The UV-209 tube has an output rating of 10,000 watts, or 10 kilowatts,which is a conservative one and does not include the circuit losses. The highest plate voltage that should be used is 10,000 volts. The direct current in the plate circuit when operated at full load is between 1.4 and 1.5 amperes. The filament should be operated with a potential of 21 volts, and with a filament current of close to 51 amperes. The grid current when the tube is oscillating should be between .06 and .13 ampere. The amplification factor is close to 40.

When new adjustments are being made, the plate voltage should be reduced until it is apparent that the new connections are satisfactory. If possible, the center tap should be grounded on the secondary winding of the filament-heating transformer. A voltmeter should be connected directly across the filament leads to facilitate setting of the filament voltage to the rated value. With care the life should well exceed 2 000 hours.

CONSTRUCTION OF RECEIVING SETS

RECEIVING APPARATUS AND CALCULATIONS

INTRODUCTION

1. The proper installation of suitable apparatus at a radio receiving station requires not only a good knowledge of the fundamental principles of the radio science, but also a certain amount of practical knowledge, skill, and judgment. The experimenter must know what is required, and then procure the necessary apparatus and assemble it in a most efficient manner. Each detail of the installation should be carefully considered, and all work must be planned before starting the actual assembly of the set and associate apparatus. If the receiving set is intended for telephone work only, the experimenter should take into consideration the wave-lengths or frequencies that are used in the work. If, for example, the range in radio telephone work is between 250 and 600 meters, or 1,200 and 500 kilocycles, the receiving set should be able to respond equally well to the limiting and to the intermediate wave-lengths or frequencies. On the other hand, if the receiving set is to be used for both telephone and telegraph work, provision should be made to be able to receive on a larger range of wave-lengths.

2. The first consideration is the type and the size of the antenna. If it is practical to construct an outside antenna of the **L** or **T** type, the length and height as well as the other characteristics affecting the wave-length must be calculated or measured. The same would apply to an indoor antenna of the L or T type. Loop, or coil, aerials may be more easily constructed to suit any desired wave-length range.

The apparatus used in the radio set should be of good quality if satisfactory results are desired. This does not imply that the most expensive set or its constituent parts will give the best results. Such is frequently the case, but all things considered, the best results are secured when properly designed and constructed apparatus is employed. Defective material, either in design or construction, often possesses properties that make it entirely unsuitable for radio apparatus. Such material is also apt to have a serious detrimental effect on the operation of the whole set. Even if a piece of apparatus does operate over the full desired range, it may not operate to best advantage over a part of that range.

3. Next in importance to the quality of radio apparatus is the care with which the set may be assembled. It is pleasing to see a set with the parts properly located, and the wiring done in a neat and orderly manner. And not only is the appearance of a radio set enhanced by good assembly but its operation will be much better if considerable care is taken in assembling the various parts. The mechanical appearance of the set should be pleasing; it is more important, however, that the electrical arrangement of the component devices, as also the wiring, should be properly planned and executed. It is advisable to try out various circuit arrangements with temporary connections before wiring the receiving set permanently.

ANTENNA DESIGN

WAVE-LENGTH AND FREQUENCY

4. Every radio circuit has two predominating elements called the inductance and the capacity. These elements may either be distributed throughout the length of the circuit, or grouped as units in different portions of the circuit. In an antenna system one or the other of the two elements predominates in the circuit. In the usual outside antenna, as the **L** or the **T** type, the capacity is the predominating element, while in a loop antenna system, the inductance is the outstanding characteristic. However, in both systems, the two elements are usually present, even though these may be unequally distributed.

There is always a signal frequency to which a given antenna will respond the best. At this frequency the antenna is said to be in resonance, and, other conditions being equal, maximum signal strength will obtain in the receiving system. The resonance frequency of an antenna is usually given in terms of *wave-length in meters*, or *kilocycles per second*. A kilocycle consists of 1,000 cycles of alternating current. The frequency in kilocycles may be found by the formula

$$f=\frac{300,000}{\lambda} \qquad (1)$$

in which f = frequency, in kilocycles;
λ = wave-length, in meters (Greek letter *lambda*).

The fundamental or natural wave-length of an antenna may be determined by the formula

$$\lambda=1,885\sqrt{L\,C} \qquad (2)$$

in which λ = wave-length, in meters;
L = inductance, in microhenrys;
C = capacity, in microfarads.

This formula is slightly inaccurate in antenna calculations, and actual measurements should be made if the exact wave-length is desired.

FLAT-TOP ANTENNA DATA

5. The wave-length of a flat-top antenna depends primarily on the length of the horizontal and vertical conductors. These, however, are not the sole determining factors of the antenna wave-length. Objects within the antenna field, such as trees and buildings, have a modifying effect on the wave-length of an antenna. The diameter of the antenna conductors and the spacing between the conductors, if a multiple-wire

TABLE I

INVERTED L-TYPE ANTENNAS
FOUR-WIRE—TWO-FOOT SPACING

Horizontal Length, in Feet	Wave-Length, in Meters, for the Following Heights, in Feet, to the Flat-Top Portion				
	30	40	60	80	100
30	69	81	108	134	158
40	81	95	122	146	172
50	95	109	134	160	186
60	108	121	148	173	199
70	121	133	161	188	212
80	133	147	174	199	225
90	146	159	187	212	240
100	159	172	200	226	252
110	171	185	213	240	265
120	184	199	226	252	279

TABLE II

T-TYPE ANTENNAS
FOUR-WIRE—TWO-FOOT SPACING

Horizontal Length, in Feet	Wave-Length, in Meters, for the Following Heights, in Feet, to the Flat-Top Portion				
	30	40	60	80	100
60	77	92	124	152	180
80	92	106	139	166	196
100	106	121	154	181	211
120	121	136	169	198	228
140	135	150	184	215	243
160	149	165	198	229	259
180	163	179	213	245	275
200	178	194	229	260	291
220	192	209	244	276	306
240	206	224	257	291	322

antenna, will also change the theoretical wave-length of the antenna. The effect of a transformer winding in the lead-in will raise the wave-length to an extent dependent upon the inductance of the winding.

The Tables I and II give approximate wave-length values for flat-top antennas of various heights and lengths. The values were obtained by calculating the wave-lengths of flat-top antennas made of No. 14 B. & S. gauge copper wire.

RECEIVING-SET ANTENNAS

6. Antennas for the reception of long wave-length signals at commercial radio stations are occasionally designed for receiving signals on certain specified wave-lengths. Very often commercial, and practically always the shorter wave-length receiving antennas, are used for the reception of signals over a considerable range of wave-lengths. In sending, or transmitting, antennas, a considerable local loss of energy occurs if the antenna circuit has to be considerably tuned by loading condensers or inductances, while this feature is not important in receiving work.

A receiving antenna having a single wire not exceeding 150 feet in horizontal length will be very effective in general reception work on wave-lengths below 600 meters, although higher wave-length signals may be received by loading the circuit with inductance coils. This type and size of antenna is most satisfactory when used with a very selective receiving set, or in localities remote from strong transmitting stations. An antenna 50 to 75 feet in total length will give better service on the usual type of receiver, especially in cities where there are powerful transmitting stations that it may be desirable to tune out. For receiving sets that are inherently not selective, or in locations close to strong transmitting stations, an antenna 20 to 30 feet long will generally prove most effective. It is true that the strength of the signal will be somewhat weaker with the shorter antennas, but this is unavoidable if selectivity is the main feature desired. The actual tuning of the antenna system is then accomplished usually by taps on the inductance coil, and sometimes with the aid of a condenser.

The size of the antenna wire and the material of which it is made affect to some extent the intensity of a radio signal. An antenna used for receiving purposes only, may be constructed of stranded wire (7 strands, No. 22 B. & S. gauge hard-drawn copper wire), or of No. 14 B. & S. gauge hard-drawn copper wire. No. 17 B. & S. gauge copperclad wire is also satisfactory for this purpose.

The lead-in and the ground wire may be of the same material as the horizontal antenna wire. Care should be taken in bringing in the lead-in and ground wires that they come not nearer than 4 inches to the side of buildings or walls. No special precautions are required for indoor antennas.

ANTENNA PROTECTION

7. Ground Switch.—Early radio practice decreed that the outdoor antenna should be connected to ground by a high-voltage switch when the set is not in use. One type of such a switch is shown in Fig. 1. To the hinge jaw, or the terminal to which the switch blade is permanently attached, is connected the lead-in wire. One of the end terminals, or

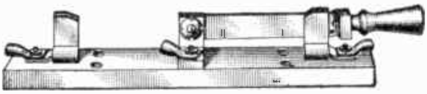


FIG. 1

break jaws, of the switch is connected to the antenna terminal of the receiving set, and the other break jaw is connected to the ground and to the ground terminal on the receiving set. When the set is in use, the switch blade is inserted into the jaw that is connected to the antenna terminal of the receiving set.

Such a switch is required in transmitting stations, but is very seldom used in receiving stations. This switch is good protection but rather superfluous with an antenna used only for receiving when simpler means serve the same purpose.

8. Lightning Arrester.—Lightning arresters are of various types. The general principle of operation is based on the discharge of electrical charges across a gap. The distance between points, or sparking surfaces, of an arrester seldom exceeds $\frac{1}{8}$ inch. One type of arrester is shown in Fig. 2. It has a clip at each end, each of which is connected to one of the sparking disks of the arrester. The two small metal disks are separated about $\frac{3}{32}$ of an inch and are placed within the porcelain jacket. The lead-in wire passes through the upper clip of the arrester and is extended to the antenna terminal on the receiving set. Similarly, the ground conductor is passed through the lower clip of the arrester and extended to the ground terminal of the receiving set. A porcelain jacket protects the unit from moisture when the arrester is mounted outdoors.

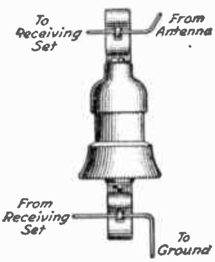


FIG. 2

To be most useful, the arrester should permit a discharge to take place between the antenna and the ground without serious injury to itself if abnormal voltage conditions are present. Most arresters will drain the antenna of heavy static charges without injury, but the rare direct lightning stroke will generally disrupt the arrester. Some lightning arresters have a saw-tooth arrangement at the sparking ends to lower the voltage at which the discharge takes place. A gas which ionizes readily, such as argon or neon, surrounding the sparking disks, also helps to lower the flash-over voltage.

COIL ANTENNAS

9. **Types of Coil Antennas.**—A coil antenna, or loop, is an enlarged coil that, when used with a suitable condenser, results in a closed oscillating circuit. One type of coil antenna is made by winding the wire on a supporting frame that will hold the wires in the form of a four-sided helix. This type of antenna is shown in Fig. 3. All of the turns wound on a coil antenna of this form have similar dimensions. This style of winding is the most common and is used almost exclusively in the larger coil antennas.

Another type of coil antenna is shown in Fig. 4. The wire is wound as a flat spiral on a frame with the successive turns or convolutions decreasing in size toward the center. The wire is carried in slots or holes in the four supports of the coil. The coil antenna of Fig. 4 is provided with a supporting base over which may be seen a dial with an extension handle. By means of the handle the loop may be turned in any desired direction, and the figures on the dial will indicate for future reference the direction of the stations heard. It is of consider-

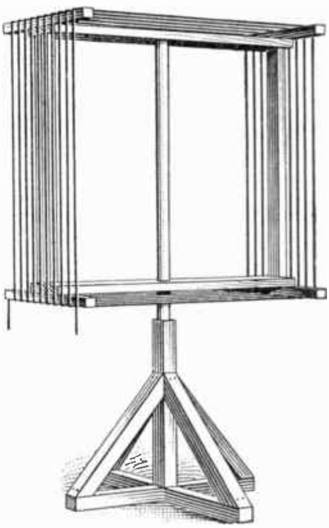


FIG. 3

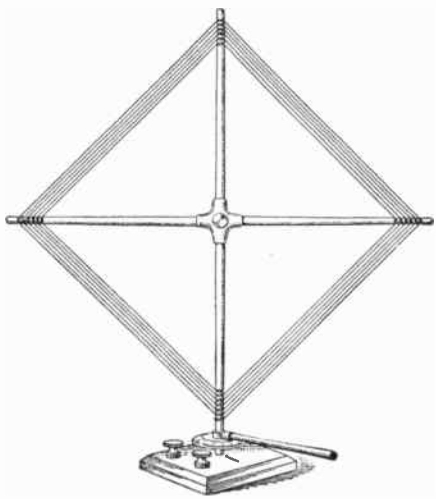


FIG. 4

able advantage to mount the wires of the coil antenna as taut as possible so as to prevent excessive vibration.

10. Coil Wire and Insulation.—The wire used in winding a coil antenna should be large enough to possess sufficient mechanical strength and its resistance should be as small as possible so as not to affect adversely the signal strength. The sizes usually used in the construction of coil antennas are Nos. 18 to 22 B. & S. gauge. Solid copper wire is generally used in this type of antenna. Good Litz wire, that is, fine-strand wire having each strand continuous throughout its length, is preferable. However, should one of the strands break, the reception of signals would be somewhat impaired.

The contact between the wire and the supporting framework of a coil antenna should be at a minimum number of points, and

TABLE III

SAME LENGTH OF WIRE WOUND ON COIL-ANTENNA FRAMES OF DIFFERENT SIZES

Length of Each Side, in Feet	Total Number of Turns	Spacing of Wires, in Inches	Inductance, in Mirco-henrys	Capacity of Coil, in Micro-farads	Fundamental Wave-Length, in Meters
8	3	.5	96	.000075	160
6	4	.25	124	.000066	170
4	6	.25	154	.000055	174
3	8	.125	193	.000049	183

only the best quality insulating material should come in contact with the conductor. If the quality of the frame insulation is doubtful, insulated copper wire should be used for winding the coil. Bare wire may be used when the insulation of the frame is known to be good, and then only when the antenna is to be used indoors. Sometimes colored insulation is used

TABLE IV

WAVE-LENGTHS OF 5-FOOT COIL ANTENNAS

Number of Turns	Spacing of Wires, in Inches	Condenser Capacity, in Microfarads, Across Coil Terminals		
		.00004	.00065	.0014
4	.5	200	400	650
8	.5	350	700	950
16	.5	500	1,000	2,300

on the conductor to enhance the appearance of the coil. This is sometimes objectionable, for certain coloring materials reduce the insulation qualities of the covered wire. Enamel covered wire is frequently desirable, because its insulating qualities are usually good, and the enamel coating prevents the wire from turning a darkish color.

11. Coil-Antenna Data.—For convenience in determining the size of the frame and the number of turns of wire required for a coil antenna the accompanying tables may be used. To indicate the manner in which the wave-length is affected by the size of the frame, the number of turns of wire, and the spacing between the wires, the values of Table III have been calculated. For each size of frame, the same length of wire is used, namely 96 feet. In Table IV are given the

TABLE V

APPROXIMATE WAVE-LENGTH OF 4-FOOT COIL ANTENNAS WITH VARIOUS VALUES OF CONDENSER CAPACITY ACROSS THE COIL TERMINALS

Number of Turns	Condenser Capacity, in Microfarads						Distribution in Slots ½ Inch Apart
	.00005	.0001	.0005	.001	.002	.003	
1		65	128	178	250	310	1 turn per slot
3	130	155	290	400	550	675	1 turn per slot
6	230	280	500	710	1,000	1,200	1 turn per slot
12	430	490	920	1,250	1,700	2,050	1 turn per slot
24	760	880	1,600	2,100	3,000	3,600	1 turn per slot
48	1,550	1,775	3,150	4,300	6,000	7,000	2 turns per slot
72	2,200	2,650	4,800	6,400	8,800	11,000	3 turns per slot
120	3,930	4,500	7,900	10,000	14,700	17,700	5 turns per slot
240	7,600	9,000	15,650	20,500	27,200	32,900	10 turns per slot

wave-length values of a 5-foot coil, and in Table V are given the wave-length values of the more common 4-foot coil antenna with various numbers of turns.

MEASUREMENT OF NATURAL WAVE-LENGTH, INDUCTANCE, AND CAPACITY OF ANTENNA

12. The wavemeter *a* in Fig. 5 has buzzer excitation, and is coupled loosely to the single turn *b* in the antenna circuit. An *aperiodic*, or untuned, receiving circuit *c* is coupled loosely to receive energy from the antenna through the coil *d*. The resonance frequency of the receiving circuit *c* is so remote from the resonance frequency of the antenna circuit that the receiving circuit *c* can be considered as aperiodic. So as not to receive any signal directly from the wavemeter circuit, the wavemeter and detector circuits are arranged at right angles to each other and at some distance apart.

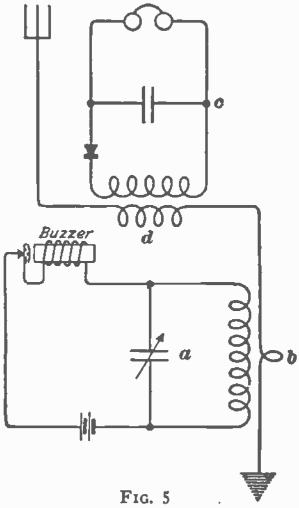


FIG. 5

The current from a buzzer circuit is used to excite the wavemeter *a*. The wavemeter must be calibrated with the buzzer so that the wave-length or frequency of the radiated wave may be accurately read from the condenser setting. The antenna coil *d* should have about as much inductance as is possessed by the antenna system and may consist of a tapped coil. An aperiodic receiving circuit *c*, often of a large fixed capacity and a relatively small fixed inductance, is most convenient for determining when a state of resonance exists between the wavemeter and antenna circuits which is indicated by a maximum signal strength at that point. A circuit that must be tuned with each wave-length change may be employed, but it is apt to introduce errors of its own.

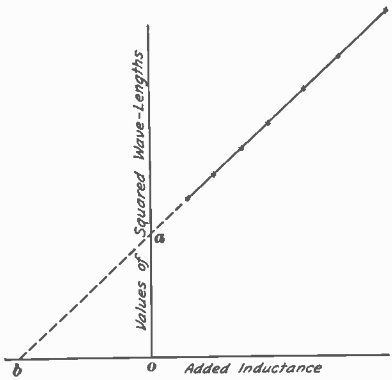


FIG. 6

Start the buzzer and listen in on the receiving circuit. Set the wavemeter at some desired wave-length and adjust the antenna to resonance or until a maximum sound is heard in the telephone receivers. If a fixed antenna coil is used, the wavemeter circuit is tuned to resonance with the antenna system. In either case the wave-length and the value of the inductance that has been added to the antenna circuit are read and recorded.

13. For accuracy the wave-length measurements should be repeated from six to eight times with adjustments over a wide range of values. The readings of wave-length should be squared, and these numbers plotted against the readings of added inductance, as shown in the upper right-hand portion of Fig. 6. If the readings have been carefully taken, the plotted points should lie on a straight line. This line should be extended to intersect the wave-length squared axis at a, and the inductance axis, or reference line, at b. The value $O\,a$ then represents the square of the natural wave-length of the antenna only. As an example, if the value of $O\,a$ is 40,000, which is the square of 200, the natural wave-length will be 200 meters. The inductance of the antenna is determined by the intersection of the straight line with the added inductance line. Thus, if the numerical value of $O\,b$, as read on the scale to the left of O, is -65 microhenrys, it would show that the inductance of the antenna is 65 microhenrys.

The electrical capacity of the antenna system may be found by the use of the formula

$$C=\frac{\lambda^2}{3{,}553{,}000\times L}$$

in which C = capacity, in microfarads;
L = inductance, in microhenrys;
λ = wave-length, in meters.

Assuming the value of L as 65 and the value of λ as 200, the capacity will be

$$C=\frac{(200)^2}{3{,}553{,}000\times 65}=.000173 \text{ microfarad.} \quad \text{Ans.}$$

WIRE DATA

METAL-COATED WIRE

14. Various metal coatings have been applied to copper wire, and a copper coating on wire made of other metal. A thin coating of tin on copper makes it easier to solder the wire. To add to the appearance of the wiring, gold plating has been used on the copper wires inside a receiving set. Some of the

TABLE VI

COMPARATIVE VALUES OF MECHANICAL STRENGTH AND ELECTRICAL RESISTANCE OF COPPERCLAD AND COPPER WIRE

Size B. & S. Gauge	Average Breaking Load, in Pounds		Direct-Current Resistance, Ohms per 1,000 Feet at 68° F.		
	Copperclad	Copper	30 Per Cent. Copperclad	40 Per Cent. Copperclad	Copper
8	1,200	828	2.13	1.60	.641
9	970	663	2.69	2.02	.808
10	800	528	3.39	2.55	1.02
11	645	423	4.28	3.21	1.29
12	520	337	5.39	4.05	1.62
13	415	268	6.80	5.11	2.04
14	330	214	8.58	6.44	2.58
15	275	170	10.8	8.13	3.25
16	210	135	13.7	10.2	4.10
17	170	108	17.2	12.9	5.17
18	140	86	21.7	16.3	6.51
19	110	68	27.4	20.5	8.21
20	90	54	34.5	25.9	10.4

coating materials tend to raise the high-frequency resistance of the wire, but not as much as does the oxidation of copper wire when it has been in use for some time.

Copperclad wires of various kinds have a steel core and a thin outside covering of copper. The copper may be poured, while melted, around the steel ingot or casting, and allowed to cool. The copper and steel are thus firmly fastened together and when drawn into wire there will be a good coating of copper over the full length of steel. The copper acts as a protecting coating to the steel, which will not rust when so protected. The electrical resistance of the copperclad steel wire thus formed is somewhat higher than that of solid copper of the same outside diameter, but the mechanical strength of the copperclad steel wire is considerably greater than that of the solid copper wire. The copperclad steel wire is also somewhat cheaper than solid copper wire of the same size. Due to skin effect, only the outside of a conductor carries high-frequency current, so the electrical resistance of copper-clad steel wire may not be appreciably greater than that of solid copper when carrying radio-frequency currents.

In Table VI are given values of the mechanical strength and electrical resistance of copperclad wire as compared with corresponding values of copper wire.

RESISTANCE VARIATION WITH FREQUENCY

15. Skin effect causes the apparent resistance of a conductor to be much greater with high-frequency alternating

TABLE VII

RATIO OF HIGH-FREQUENCY TO DIRECT-CURRENT RESISTANCE

Diameter of Wire		Frequency, in Cycles per Second					
Millimeter	Mils	60	100	1,000	10,000	100,000	1,000,000
.05	1.869						1.001
.10	3.937					1.001	1.008
.25	9.343					1.003	1.247
.50	18.685				1.001	1.047	2.240
1.0	39.37				1.008	1.503	4.19
2.0	78.74			1.001	1.120	2.756	8.10
3.0	118.31			1.006	1.437	4.00	12.0
4.0	157.48			1.021	1.842	5.24	17.4
5.0	186.85		1.001	1.047	2.240	6.49	19.7
7.5	280.28	1.001	1.002	1.210	3.22	7.50	29.7
10.0	393.70	1.003	1.008	1.503	4.19	12.7	39.1

current than with direct current. This is due to the fact that at radio frequency most of the current passes in a small region next to the surface of the conductor. Table VII gives the ratio of the resistance of straight copper wires with alternating currents of various frequencies to the direct-current resistance. The value found opposite the wire size and in the desired frequency column is multiplied by the direct-current resistance for that same sized wire to give the resistance in ohms.

INSULATED WIRE DATA

16. In the winding of coils to be used in radio receiving sets, frequently the number of turns is specified. The accompanying Table VIII will be found of value in determining the length of tubing necesssary to hold the required number of turns. The total number of turns divided by the number of turns per inch will give the length of winding space required if the wire is all wound in a single layer. The amount of space required varies with the size of the wire and the kind of insulation used on the wire. For example, for a certain type of single-layer coil 150 turns of No. 22 single-cotton covered wire is required, and it is desired to know the length of tubing necessary for that number of turns. According to Table VIII, 33.9 turns of No. 22 single-cotton covered wire may be wound within a space of 1 inch. Dividing 150 by 33.9 gives 4.4, which is the length of space required in inches on a tube for 150 turns of the above designated wire.

INDUCTANCE

INDUCTANCE FORMULAS

17. The inductance is that property of a circuit which tends to oppose all changes of current in the circuit. Inductance tends to resist the establishing of current in the circuit, and when the current is established the inductance tends to maintain the current. This property of a circuit is due to the magnetic field that surrounds every conductor in which electricity is flowing. The magnetic field around a conductor is formed as soon as current is established in the circuit and this field is withdrawn when the current ceases. The inductive

TABLE VIII

RESISTANCE AND WINDING DATA

Wire Size B.&S.	Ohms per 1,000 Feet	Number of Turns per Linear Inch					
		Single Cotton	Double Cotton	Single Silk	Double Silk	Enamel	Enamel and Silk
8	.641	7.35	7.05			7.7	
9	.808	8.26	7.87			8.6	
10	1.02	9.25	8.85			9.6	
11	1.28	10.3	9.80			10.8	
12	1.62	11.5	10.9			12.1	
13	2.04	12.8	12.2			13.5	
14	2.58	14.3	13.5	15.0	14.6	15.1	14.7
15	3.25	15.9	14.9	16.9	16.5	16.9	16.5
16	4.09	17.9	16.7	18.9	18.3	18.9	18.4
17	5.16	20.0	18.5	21.1	20.4	21.3	20.5
18	6.51	22.2	20.4	23.6	22.7	23.8	22.9
19	8.21	24.4	22.2	26.4	25.2	26.5	25.8
20	10.4	27.0	24.4	29.4	28.0	29.7	28.4
21	13.1	29.9	26.3	32.8	31.0	33.1	31.5
22	16.5	33.9	30.0	36.6	34.4	37.2	35.0
23	20.8	37.6	32.7	40.7	37.9	41.5	39.0
24	26.2	41.5	35.6	45.3	41.8	46.5	43.1
25	33.0	45.7	38.6	50.3	46.1	52.1	47.9
26	41.6	50.2	41.8	55.9	50.8	58.5	52.8
27	52.5	55.0	45.1	61.8	55.6	65.4	58.1
28	66.2	60.2	48.6	68.5	61.0	73.5	64.4
29	83.4	65.4	51.9	75.2	66.2	82.0	70.6
30	105	71.4	55.6	83.3	72.5	91.7	77.9
31	133	77.5	59.2	91.7	78.7	103	85.3
32	167	83.4	62.9	101	84.8	115	93.9
33	211	90.0	66.2	110	91.7	130	103
34	266	97.1	70.0	121	99.0	145	112
35	335	104	73.5	132	106	161	123
36	423	111	77.0	143	114	180	133
37	533	118	80.0	154	121	204	146
38	673	125	83.3	167	128	227	157
39	848	135	87.0	180	137	256	172
40	1,070	141	90.9	196	145	286	185

opposition represents a storage of electrical energy while tending to oppose the current, and a liberation of an equal amount of electrical energy while tending to maintain the current. A straight piece of wire possesses a certain amount of inductance, which property of the conductor is increased when the conductor is coiled, with the successive turns close to each other.

18. Inductance of Single Horizontal Wire.—A straight piece of wire possesses a certain amount of inductance that tends to prevent changes of current in a circuit of which the conductor forms a part. The inductance of a single horizontal wire may be calculated by the formula

$$L = .002\, l \left(\log_n \frac{2h}{r} + .25\right)$$

in which L = inductance, in microhenrys;
l = length of wire, in centimeters;
h = height of wire above earth, in centimeters;
r = radius of wire, in centimeters;
$\log_n$ = natural logarithm of $\frac{2h}{r}$.

The *natural*, or *hyperbolic*, *logarithm* may be obtained by multiplying the *common logarithm* of a number, which may be found in the Section on Logarithms, by 2.303. For example, the common logarithm of 2996 is 3.47654; hence, 3.47654 ×2.303, or 8.00647 is the natural logarithm of 2996.

EXAMPLE.—What is the inductance of a No. 14 B. & S. wire, 90 feet long at a height of 40 feet?

SOLUTION.—In the preceding formula the dimensions of the wire are in centimeters; hence, it is necessary to reduce the length, height, and diameter of the wire to centimeters.

$90 \times 12 \times 2.54 = 2743.2$ cm. length of conductor,
$40 \times 12 \times 2.54 = 1219.2$ cm. height of conductor,
No. 14 B. & S. wire has a radius of .0814 cm.

Applying the foregoing formula gives

$$L = .002 \times 2743.2 \times \left(\log_n \frac{2 \times 1219.2}{.0814} + .25\right)$$

$$= 5.4864 \times \left(\log_n \frac{2438.4}{.0814} + .25\right)$$

$$= 5.4864 \times (\log_n 29{,}956 + .25)$$

The common logarithm of 29,956 is 4.47648; hence, the natural logarithm will be 4.47648×2.303, or 10.30933. Therefore, $L = 5.4864 \times (10.30933 + .25)$, or 57.93 microhenrys. Ans.

19. Inductance of a Single Vertical Wire.—The inductance of a straight single vertical wire may be found by the formula

$$L = .002\, l \left(\log_n \frac{2\, l}{r} - .75 \right)$$

in which L, l, r, and $\log_n$ have the same significance as in the formula in the preceding article.

20. Inductance of Single Circular Turn.—For a straight conductor the determination of the inductance is comparatively simple. As the conductor departs from a straight linear direction, the inductance gradually changes, so that when a complete circle is formed its inductance may be determined by the formula

$$L = .01257\, R \left[\left(1 + \frac{r^2}{8\, R^2} \right) \log_n \frac{8\, R}{r} + \frac{r^2}{24\, R^2} - 1.75 \right]$$

in which L = inductance, in microhenrys;
R = radius of coil, in centimeters;
r = radius of wire, in centimeters;
$\log_n \frac{8\, R}{r}$ = natural logarithm of $\frac{8\, R}{r}$.

21. Inductance of Single-Layer Coil.—The inductance of a closely wound single-layer coil of helical shape, having an air or some other non-magnetic core, may be found by the formula

$$L = \frac{.03948\, R^2\, n^2}{l} K$$

in which L = inductance, in microhenrys;
R = radius of coil, in centimeters;
n = number of turns;
l = length of coil, in centimeters;
K = value depending upon the ratio of $\frac{2\, R}{l}$, which may be obtained from Table IX.

EXAMPLE.—Find the inductance of a single-layer coil, 4 inches long, 2 inches in diameter, wound with No. 18 B. & S. gauge double-cotton covered wire.

SOLUTION.—From Table VIII it is found that approximately 80 turns of No. 18 double-cotton covered wire may be wound in a 4-in. space. The value of K may be determined from Table IX; substituting for $\frac{2R}{l}$ gives $\frac{2\times 1}{4}$, or .50. The value of .50 just found gives in Table IX a value for K of .818. Reducing all the dimensions given in inches to centimeters

TABLE IX

VALUES OF K

$\frac{2R}{l}$	K	$\frac{2R}{l}$	K	$\frac{2R}{l}$	K
.00	1.000	.65	.775	2.00	.526
.05	.979	.70	.761	2.50	.472
.10	.959	.75	.748	3.00	.429
.15	.939	.80	.735	3.50	.394
.20	.920	.85	.723	4.00	.365
.25	.902	.90	.711	4.50	.341
.30	.884	.95	.700	5.00	.320
.35	.867	1.00	.688	6.00	.285
.40	.850	1.10	.667	7.00	.258
.45	.834	1.20	.648	8.00	.237
.50	.818	1.40	.611	9.00	.219
.55	.803	1.60	.580	10.00	.203
.60	.789	1.80	.551		

gives: $R=1\times 2.54$, or 2.54 cm.; $l=4\times 2.54=10.16$ cm. Substituting these values for the letters of the formula, the inductance is found to be

$$L=\frac{.03948\times 2.54^2\times 80^2}{10.16}\times .818$$

$$=\frac{.03948\times 6.4516\times 6{,}400}{10.16}\times .818$$

$$=131 \text{ microhenrys.} \quad \text{Ans.}$$

INDUCTANCE COILS

22. The straight helical-type coil has been considered so far, as it offers fairly simple mathematical formulas for the calculation of its inductance. The actual and calculated values are, however, not apt to check any too closely, and for accurate work the inductance should be measured. The distributed winding takes up an unreasonable amount of space, especially when the coils have a large number of turns of moderate-sized wire. To reduce the amount of winding space and to reduce the distributed capacity, coils are often made up in various styles of winding. Since many indeterminate factors enter into the construction, it is impossible to give simple formulas which will be reasonably accurate and of general application. It should be remembered that the distributed capacity may be most easily reduced by increasing

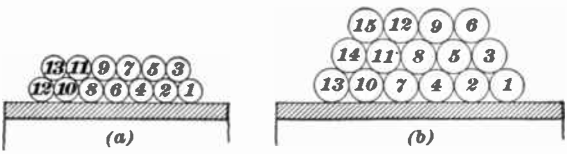


FIG. 7

the distance between adjacent turns of wire and by winding the coils so there is no large voltage or potential difference between adjacent turns.

23. Bank-Wound Coils.—The *bank winding* gets its name from the manner of winding a coil so that some of the turns are banked or wound on top of others. The coil then forms a solid winding generally two or three layers deep. The method of winding is shown in Fig. 7, where the small circles represent cross-sections of the wires and the numbers refer to the sequence of winding those particular turns. In view (*a*) is shown a double-layer winding, which means that the wire is wound in two layers, and that the length of winding space is only about one-half what it would be with a single layer. In view (*b*) is shown the sequence of turns on a triple-layer bank winding. When making this type winding great care must be exercised, and when properly wound the turns present a neat, solid arrangement.

24. Honeycomb Coils.—A *honeycomb coil*, as explained in a previous Section, derives its name from the resemblance of the winding arrangement to a honeycomb structure. In general the wires are wound so that adjacent turns in any layer are a relatively large distance apart, and the turns in adjacent layers form such an angle that the turns are as far from being parallel as possible. It is true, however, that the wires in alternate layers are parallel, and the detrimental distributed capacity is again effective to some extent. This is reduced somewhat by moving the alternate layer a little so its turns come half-way between those with which it has detrimental effects, as in the duo-lateral type of winding. This type of winding possesses such appreciably better properties than does the honeycomb type that the former is almost exclusively used. It should be remembered that honeycomb and similar coils attempt to concentrate a maximum amount of inductance in a minimum of space and without creating a high distributed capacity in the coil.

25. Honeycomb coils are often wound on circular forms or cores about 2 inches in diameter, 1 inch long, and as deep as is necessary for the required number of turns. For winding, a form should have eleven to nineteen pins in each row at the ends of a spool, with the pins at each end spaced radially much like the spokes of a wheel. The winding is then started at any point and crossed diagonally to the sixth or some other pin on the opposite side, around which a partial turn is made. The wire then progresses diagonally across again to the sixth pin, if that number is used, and after making a partial turn continues on around the spool in its zigzag course. The same number of pins are passed with each crossing of the wire, so as to make a symmetrical winding. If correctly done, a layer will be completed with one turn at each pin. The winding process would be continued layer by layer until the desired number of turns were wound on the coil. The pins should be removed from the form after the winding is completed. To make a more open construction a smaller number of pins would be passed, and a smaller number of turns would be wound in each layer. This would also give a larger number of layers for a coil with a given number of turns. As the voltage difference between adjacent wires is small, there is generally very little insulation on the wire,

TABLE X

HONEYCOMB-COIL DATA

Number of Turns in Coil	Size of Wire B. & S. Gauge	Inductance, in Millihenrys	Distributed Capacity, in Micro-microfarads	Natural Wave-Length, in Meters	Wave-Length With the Following Shunt Condenser Capacities, Microfarads			
					.001	.0005	.00025	.00001
25	24	.038	26.8	60	372	267	193	131
35	24	.076	30.8	91	528	378	277	188
50	24	.150	36.4	139	743	534	391	270
75	24	.315	28.6	179	1,007	770	560	379
100	24	.585	36.1	274	1,470	1,055	771	532
150	24	1.29	21.3	313	2,160	1,546	1,110	746
200	25	2.27	18.9	391	2,870	2,050	1,470	980
250	25	4.20	22.9	585	3,910	2,800	2,020	1,355
300	25	6.60	19.0	669	4,900	3,490	2,510	1,670
400	25	10.5	17.4	806	6,160	4,400	3,160	2,095
500	25	18.0	17.3	1,052	8,070	5,750	4,140	2,740
600	28	37.5	19.2	1,600	11,600	8,300	5,980	3,980
750	28	49.0	18.3	1,785	13,300	9,500	6,830	4,540
1,000	28	85.3	16.8	2,260	17,600	12,500	9,000	5,950
1,250	28	112.0	15.5	2,490	20,100	14,300	10,250	6,780
1,500	28	161.5	15.8	3,000	24,200	17,200	12,350	8,150

often a single-cotton covering. Machine-wound coils are wound with guides that space the wires properly without the use of pins in the form.

In Table X are given approximate values of inductance, distributed capacity, and wave-lengths applying to honeycomb coils under various conditions. These values are subject to considerable variation due to manufacturing differences. They also apply quite well to duo-lateral coils. With this table it is possible to determine the size of coil necessary to cover a given wave-length range and the proper condenser to accompany it.

26. Spider-Web Coils.—The *spider-web* type of winding also derives its name from the resemblance of the winding to a spider web as shown in Fig. 8. A piece of sheet fiber may be cut with about seven to fifteen radial slots. The wire is then wound back and forth through alternate slots, which produces an inductance unit occupying little space. This type of construction gives a very good concentrated inductance with a low distributed capacity, and is often used in practice.

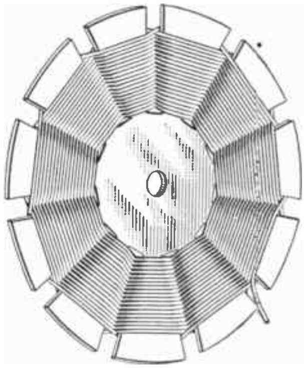


FIG. 8

27. Giblin-Remler Coils and Others.—The *Giblin-Remler coils*, one of which is shown in Fig. 9, are multi-layer coils with the adjacent wires separated by zigzag strands of cotton. They somewhat resemble honeycomb coils, and seem to possess some advantages over them. Wave-length data for the Giblin-Remler coils are given in Table XI.

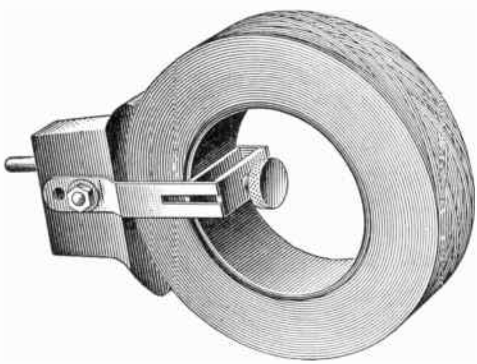


FIG. 9

A special type of coil, known as a double-D coil, has the turns wound in the shape of the letter D. These coils are sometimes used in compact variometers where each section consists of two coils with their flat sides close together. The four coils forming the variometer are then connected so as to give a maximum inductance variation

There are many other types of inductance coils, some of which embody excellent operating principles. They may

TABLE XI

GIBLIN-REMLER COILS

Number of Turns	Inductance in Milli-henrys at 1,000 Cycles	Natural Wave-Length, in Meters	Distributed Capacity, in Micro-microfarads	Wave-Length Range, in Meters, Using Condenser of .001 Microfarad, Maximum, and .00004 Microfarad, Minimum		High-Frequency Resistance in Ohms at Wave-Length Shown			
				Min.	Max.	200	500	1,000	2,000
20	.030	39	14.3	63	334		1.1		
25	.041	47	15.2	75	389		1.5		
35	.083	87	25.4	128	550		3.5		
50	.169	114	21.6	185	785		8.8	4.4	
75	.377	163	19.8	266	1,170		28.3	12.1	6.2
100	.666	217	19.9	358	1,550		80.3	26.8	12.6
						1,000	2,000	5,000	10,000
150	1.503	281	14.8	512	2,320	69.8	23.8	7.1	
200	2.68	374	14.7	690	3,110		50.6	12.5	
250	4.20	424	12.1	860	3,880		87.5	19.9	
300	6.11	494	11.2	1,030	4,680		141.	29.3	13.8
400	11.04	618	9.7	1,380	6,300			54.6	22.3
500	17.50	747	9.0	1,730	7,900			93.1	34.9
						2,000	5,000	10,000	20,000
600	29.2	1,024	10.1	2,260	10,250		111.	43.8	
750	39.0	1,249	11.3	2,660	11,850			64.	
1,000	71.6	1,620	10.3	3,570	16,000			123.	
1,250	108.0	1,930	9.7	4,380	19,700				
1,500	159.8	2,300	9.3	5,300	23,800				

perform special functions in a circuit or set, but generally have a rather limited application.

CAPACITY

MEANING OF CAPACITY

28. Capacity, like inductance, is a property of electrical circuits. The function of a condenser is to store a certain amount of electric energy in the form of a charge when the voltage applied to the condenser is increasing; this charge either in part or whole is delivered back to the circuit when the applied voltage is decreasing. Any two conductors separated by an insulating medium, called the dielectric, constitute a condenser. The capacity of a condenser depends on the size of the conductors or conducting plates, on the distance of separation between the conducting plates, and on the nature of the dielectric.

Capacity in a circuit may be either distributed throughout the entire circuit, as is the case in the antenna circuit of a radio station, or it may be grouped or concentrated in one particular location. In the usual condenser the capacity is concentrated in the condenser itself. The use of condensers in a circuit concentrates most of the capacity of the circuit. The capacity of a condenser may either be a fixed quantity as in a fixed condenser, or be varied as in a variable condenser.

The unit of capacity is the **farad**. This, however, is too large a unit for ordinary calculations; hence, the microfarad, or $\frac{1}{1,000,000}$ farad, the micro-microfarad, or $\frac{1}{1,000,000}$ microfarad, and the centimeter of capacity, or 1.11 micro-microfarad are more frequently found in radio calculations.

CAPACITY FORMULAS

29. Capacities in Parallel and in Series.—When condensers are connected in parallel, their combined capacity is equal to the sum of their individual capacities. For two condensers in parallel this may be expressed by the formula

$$C = C_1 + C_2 \qquad (1)$$

in which C equals the combined capacity and C_1 and C_2 the capacities of the individual condensers, all values being in the same units of capacity.

When condensers are connected in series their combined capacity equals the reciprocal of the sum of the reciprocals of the individual capacities. For two condensers in series this may be expressed by the formula

$$C=\frac{1}{\frac{1}{C_1}+\frac{1}{C_2}} \qquad (2)$$

in which C, C_1, and C_2 have the same meaning as in formula **1.**

EXAMPLE.—Find the combined capacity of two condensers each having a capacity of 2 microfarads connected in: (*a*) parallel; (*b*) series.

SOLUTION.—(*a*) $C=2+2=4$ microfarads. Ans.

(*b*) $C=\frac{1}{\frac{1}{2}+\frac{1}{2}}=\frac{1}{1}=1$ microfarad. Ans.

30. Capacity of Single Horizontal Wire.—The capacity of a single horizontal wire in conjunction with the earth, which forms the second plate of the so formed condenser may be determined by the formula

$$C=\frac{l}{2\log_n \frac{2h}{r}}\times 1.1$$

in which C = capacity, in micro-microfarads;
l = length of wire, in centimeters;
h = height of wire above earth, in centimeters;
r = radius of wire, in centimeters;
$\log_n$ = natural logarithm of fraction following the symbol.

EXAMPLE.—Find the capacity of a single wire No. 14 B. & S. gauge, 90 feet long and 40 feet high.

SOLUTION.—Reducing the dimensions given in feet to centimeters, as required by the formula, gives: $90\times 12\times 2.54=2{,}743.2$ cm.; $40\times 12\times 2.54=1{,}219.2$ cm. No. 14 B. & S. wire has a radius of .0814 cm. Then,

$$C=\frac{2{,}743.2}{2\log_n \frac{2\times 1{,}219.2}{.0814}}\times 1.1=\frac{3{,}017.52}{2\log_n 29{,}956}$$

$$=\frac{3{,}017.52}{20.61867}=146 \text{ micro-microfarads. Ans.}$$

31. Capacity of Single Vertical Wire.—The capacity of a single vertical wire may be determined by the formula

$$C = \frac{l}{2 \log_n \frac{l}{r}} \times 1.1$$

in which the letters C, l, and r and the expression $\log_n$ have the same significance as in the preceding case.

32. Capacity of Two-Plate Condenser.—The simplest type of condenser is one consisting of two conducting plates separated by a suitable dielectric. The capacity of such a condenser may be found by the formula

$$C = \frac{.0885\ K\ A}{t}$$

in which C = capacity, in micro-microfarads;

A = surface area of one side of one of the plates, in square centimeters;

t = thickness of dielectric, in centimeters;

K = specific inductive capacity, which for any given substance may be found in Table XII.

EXAMPLE.—Calculate the capacity, in microfarads, of a condenser consisting of two plates each 5 and 10 centimeters in width and length, respectively, separated by a sheet of mica .03 centimeter thick, and having a dielectric constant 5.

SOLUTION.—Substituting the values given in the example for the letters of the formula gives

$$C = \frac{.0885 \times 5 \times (5 \times 10)}{.03}$$

$$= \frac{22.125}{.03}$$

= 738 micro-microfarads, or .000738 microfarad. Ans.

33. Capacity of Multi-Plate Condenser.—The capacity of a condenser consisting of more than two similar plates may be found by the following formula

$$C = \frac{.0885\ K\ A\ (n-1)}{t}$$

in which C, K, A, and t have the same significance as in the preceding formula, and n = number of plates.

34. Maximum Capacity of Variable Condensers.—Variable condensers of various types may be found in actual use. In one type of variable condenser consisting of two

TABLE XII

ELECTRICAL PROPERTIES OF COMMON INSULATING MATERIALS

Material	Megohms per Centimeter Cube	Specific Inductive Capacity K	Dielectric Strength A.-C. Volts per Mil
Air, atmospheric pressure		1.00	10–75
Air, pressure 100 atmospheres		1.05	higher
Air, vacuum .001 mm. pressure		.94	lower
Asbestos		2.5–3.0	
Bakelite		4.0–8.8	200–1,100
Celluloid	2×10^{4}	4.2–16	400–900
Fiber, treated			700–1,100
Glass	2×10^{7}	3.5–10	150–300
Ice		3.0	
Marble		8–9	50–100
Mica	2×10^{11}	2.5–7.5	700–1,500
Molded composition			40–360
Oils		2.0–4.8	100–400
Paper, dry		1.5–4.6	100–230
Paraffin	1×10^{10}	1.7–2.5	200–300
Porcelain	3×10^{8}	4.4–6.8	30–120
Rubber		2–4	250–500
Rubber, hard	1×10^{12}	2–3.5	500–1,500
Shellac		3–4	
Varnished cambric		3.5–5.5	500–1,300
Water (18° C.)		81.07	
Wood, dried		2.5–7.5	10–50

circular plates, the capacity is varied by varying the distance between the plates. The maximum capacity of such a condenser may be calculated by the formula for a fixed two-plate condenser. The area of the circular surface of one side of one of the plates may be found by multiplying the square of the radius by 3.1416.

35. Another type of variable condenser consists of two sets of semicircular plates, one set of which is stationary and the other is movable. The capacity of this type of condenser is varied by turning the movable set of plates within the spaces between the stationary plates. When the movable plates are enclosed within the stationary plates, the capacity of the condenser is maximum and may be calculated by the formula,

$$C = \frac{.139\, K(n-1)\,(r_1^2 - r_2^2)}{t}$$

in which C, K, n, and t have the usual significance and

r_1 = outside radius of plates, in centimeters;

r_2 = inner radius of plates in centimeters; the inner radius is usually very small compared with the outside radius.

EXAMPLE.—What is the maximum capacity, in microfarads, of a 23-plate variable air condenser of semicircular plates 4 inches in diameter, with a separation between the plates of $\frac{1}{16}$ inch, and the inner diameter is $\frac{1}{2}$ inch?

SOLUTION.— $r_1 = \frac{4}{2} \times 2.54 = 5.08$ cm.; $r_2 = \frac{.5}{2} \times 2.54 = .635$ cm.; $n = 23$; $t = \frac{1}{16} \times 2.54 = .16$ cm.; and $K = 1$; hence,

$$C = \frac{.139 \times 1 \times (23-1) \times (5.08^2 - .635^2)}{.16}$$

$$= \frac{77.68}{.16} = 485 \text{ micro-microfarads, or } .000485 \text{ microfarad. Ans.}$$

INSULATING MATERIALS

36. Insulating materials are those substances which offer a relatively high opposition to the passage of an electric current. A vacuum, or even dry air, is almost a perfect insulator, but is not usable under all circumstances, especially where conductors must be supported. Similarly, one material is not available for universal application, as sometimes an insulator must function under excessive moisture, heat, or mechanical stress. At other times the insulating material need be only a cheap protective coating. The particular requirements of the case determine to a considerable extent the nature of the insulating material to use.

In Table XII, besides the specific inductive capacities of various materials, are also given some resistance values. The values are given in megohms per centimeter cube, which is the usual unit, and means the resistance in millions of ohms between the opposite sides of a cubic centimeter of the insulating material. For example, if a material had a value of 4 megohms per centimeter cube, its resistance would be 4,000,000 ohms between the opposite faces of a cubic centimeter of that material. The exponents in the table mean that that is the power of the number. The value 2×10^4 means that the number is $2\times 10{,}000$, or 20,000. Similarly 2×10^7 means that the value is actually $2\times 10{,}000{,}000$, or 20,000,000. Values for all the materials listed are not available in accurate form.

37. An important feature, or property, of insulating materials is their ability to resist break-down or puncture by high voltages. In the table just referred to will be found values for many materials in common radio and electrical use. It is well to note that the values are given in volts per mil, which means that the number given represents the voltage necessary to puncture a specimen of the material one mil thick. In some cases, readings were taken on much thicker samples, and volts per mil were calculated from the measured thickness. The actual volts per mil required to puncture a thin specimen is generally much higher than that required to puncture a thick one. This seems true because of the fact that uneven stresses are set up in the dielectric, and the material is not always entirely homogeneous. Moisture, especially with porous material, reduces the dielectric strength to a considerable extent.

RADIO RECEIVING CIRCUITS

INDUCTANCE AND CAPACITY

38. Whenever reference is made to a radio circuit two elements of that circuit are usually taken into consideration, namely, the inductance and the capacity of the circuit. These two elements determine the frequency of the circuit. Inductance and capacity are not always concentrated in the circuit. For example, the antenna possesses both inductance and capacity. The coils used in radio receiving sets are there mainly for their inductance; sufficient capacity, however, may be found between the turns of the winding so as to make the coil itself in some instances a complete oscillating circuit. The capacity between adjacent parallel wires modifies to some extent the natural period of a radio circuit. The resistance of a radio circuit decreases the amplitude of the current but it does not affect greatly the frequency of that circuit.

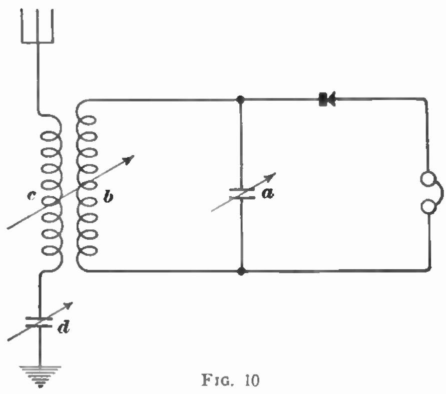


Fig. 10

SECONDARY OF SIMPLE RADIO SET

39. Inductance Coil.—When considering the design of a set it is best to start with a circuit whose values can be easily and accurately calculated. In a standard tuner, such as shown in Fig. 10, that is tuned by a shunt condenser *a*, the inductance of the secondary winding *b* is seldom changed appreciably in tuning. The primary winding is shown at *c* and an auxiliary condenser at *d*. If the set is to operate on a wave-length range of 165 to 300 meters it may be necessary to work through the calculations two or three times until the range is covered.

Assume that the winding space is $1\frac{1}{4}$ inches long and on a tube 2 inches in diameter. With No. 24 single-silk covered wire there will be about 56 turns in the winding space allowed. The corresponding value of K, Table IX, will be found from $\frac{2R}{l}=\frac{2\times 1}{1.25}=\frac{8}{5}=1.60$, or $K=.58$. Substituting values in the formula of Art. 21 gives

$$L=\frac{.03948\times(1\times 2.54)^2\times 56^2}{1.25\times 2.54}\times .58$$
$$=146 \text{ microhenrys}$$

40. The insulation on the wire acts like a miniature condenser dielectric between adjacent turns of wire. All these small condensers across each turn of wire combine to act just like one larger condenser across the coil. This condenser in parallel with the coil gives the coil a definite wave-length of its own. In the case under consideration it is assumed that the capacity is 30-micro-microfarads, which is a reasonable value. The wave-length may be calculated by the formula

$$\lambda=1{,}885\sqrt{LC}$$
$$\lambda_1=1{,}885\sqrt{146\times .000030}$$
$$=125 \text{ meters}$$

in which λ_1 is taken as representing the natural wave-length of the coil. The minimum wave-length on which this coil can be used is 125 meters. The way to get around this difficulty, if it were to be used on shorter wave-lengths, would be to tap the coil so as to include only as many turns as are necessary.

41. Shunt Condenser.—A convenient shunt condenser *a*, Fig. 10, to combine with the coil under consideration would be one with 11 plates. Such a condenser would be likely to have at least 20 micro-microfarads capacity as a minimum value and a maximum capacity of 250 micro-microfarads, or .000250 microfarad. With the lowest possible setting of the condenser the total capacity will be that of the coil and condenser in parallel, or 30+20=50 micro-microfarads.

42. Wave-Length.—The minimum wave-length of the coil and condenser combination will be found by the wave-length formula

$$\lambda = 1{,}885\sqrt{L\,C}$$
$$\lambda_2 = 1{,}885\sqrt{146 \times .000050}$$
$$= 161 \text{ meters}$$

in which λ_2 is the wave-length of the coil and condenser with the minimum setting. This value is just below the specified lower limit of 165 meters, so it is acceptable. Had it not been low enough, a different type of condenser or another style of winding might have given the desired result.

The maximum wave-length obtainable may now be calculated from the assumed values of inductance and capacity. With a distributed coil capacity of .000030 microfarad and the maximum condenser capacity of .000250 microfarad, the total capacity will be the sum of these two values, or .000280 microfarad.

$$\lambda = 1{,}885\sqrt{L\,C}$$
$$\lambda_3 = 1{,}885\sqrt{146 \times .000280}$$
$$= 381 \text{ meters}$$

in which λ_3 is the wave-length of the coil and condenser with maximum setting. This value is well above the required maximum wave-length, so the combination will serve the purpose.

A consideration of the preceding figures will show that the wave-length range of the coil and condenser combination does not go much below the specified lower value but does cover a fairly large range above the specified upper limit. A condenser with smaller maximum capacity could be used to cover the wave-length adjustments over the required range. Such a condenser would be easier to adjust, or tune, since the capacity change would be smaller per degree of movement.

43. Use of Large Inductance and Small Capacity.—It is, in general, desirable to use a large amount of inductance with a minimum amount of capacity in a tuned circuit to secure maximum signal strength. For this reason it would be preferable to use the coil and condenser as assumed rather than to use a combination which would reach much shorter wave-lengths. If it is desired to equalize the excess range above and below the specified limits the following points should be considered. Between the lower calculated and lower specified wave-length values of 161 and 165 meters is a range of 4 meters. There is a difference of 81 meters between the upper specified and calculated values of 300 and 381 meters. From these figures there is an apparent possible variation above the required range 20 times as great as that below the lower specified value.

It is more desirable, however, to refer to tuned radio circuits in terms of frequency since it is the frequency that determines the accuracy with which the circuit may be adjusted. For example, the wave-length values of 161 and 165 meters become 1,860 and 1,820 kilocycles, respectively, with a frequency difference of 40 kilocycles. The higher wave-length values of 300 and 381 meters become 1,000 and 787 kilocycles, respectively, with a difference of 213 kilocycles between these values. The upper wave-length tuning range, corresponding with the lower kilocycle values, has a kilocycle range only a little more than 5 times as great as that at the other end of the scale. It is, therefore, well to keep in mind in design work, that the kilocycle or frequency value is often more important than the wave-length value.

PRIMARY OF SIMPLE RADIO SET

44. About the best general rule to apply in determining the primary inductance necessary to go with the secondary coil just considered, is that the primary inductance should be approximately equal to that of the secondary. This inductance coil shown at *c* in Fig. 10, is normally connected in series with the antenna, but, since the main property of an antenna is its capacity effect, the antenna capacity really acts with the coil to form a tuned circuit. If the antenna effective capacity is known, it is possible to calculate the number of turns necessary in the inductance coil to secure the right wave-length. Since the antenna capacity cannot readily be changed, except by an auxiliary condenser *d*, the primary inductance coil is customarily tapped to allow of tuning the receiving circuit. If used, the effect of the condenser *d*, connected in series with the antenna, is to make the combined capacity of the antenna and the condenser less than the capacity of the antenna alone and, therefore, to decrease the natural wave-length of the antenna circuit. To allow for variations in various antennas with which the set may be used, it is customary to include more turns than are really necessary. As there are in most cases no space limitations, the wire used on the primary is often of a larger size than that of the secondary coil.

REGENERATIVE RECEIVERS

45. Single-Circuit Regenerative Set.—The design of a so-called single-circuit regenerative receiver, the circuit diagram of which is shown in Fig. 11, will now be considered. The circuit derives its name from the use of the inductance coil *a*, which serves as an autotransformer. The variable condenser *b* reduces the total capacity of the antenna and permits of using a greater inductance to obtain the proper frequency characteristics of the antenna circuit. The coil *c* is coupled to the coil *a*, the coupling, however, being variable as indicated by the arrow across the two coils. The purpose of the coil *c* is to feed some of the energy from the plate circuit back to the grid circuit and in that manner obtain further amplification. Due to the coupling between the coils *a* and *c*, the plate-circuit coil *c* need not possess as much inductance as would be necessary to tune the plate circuit.

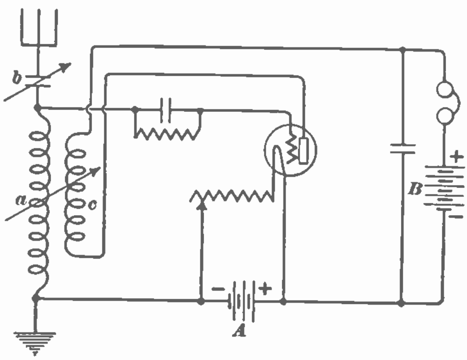


FIG. 11

The inductance coil *a* should be so arranged that its inductance might readily be changed. It may be tapped at every few turns, so as to obtain the desired inductance and then tuned to the desired frequency by means of the condenser *b*.

Assume that the circuit is arranged so as to be tuned by a variometer while a small coupling inductance and a fairly large condenser have inductance and capacity of such values as to tune the circuit to the lowest wave-length it is desired to receive. The variometer inductance should then be great enough to load the circuit so it will tune to the intermediate and longest wave-lengths.

46. Two-Circuit Regenerative Set.—In Fig. 12 is shown a circuit diagram of a two-circuit regenerative receiving set.

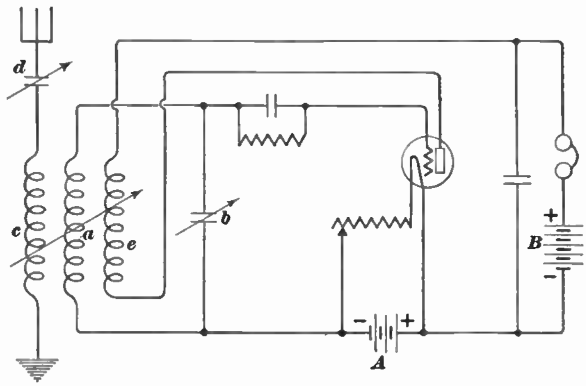


FIG. 12

This circuit does not differ appreciably from the single-circuit set just described, and the operation is practically the same. The additional tuned circuit, including the inductance coil *a* and the condenser *b*, offers certain advantages that are absent in the single-circuit set. Finer adjustment with a resultant lesser interference justifies the use of the additional circuit. Besides the increased signal strength due to regeneration, or feed-back action, and the selectivity of the set, another advantageous feature not present in the single-circuit tuner is found in the two-circuit regenerative tuner. A regenerative circuit acts as a generator of high-frequency currents. In the single-circuit set the high-frequency currents are set up in the antenna circuit, so that undesirable disturbances are produced which disturb other receiving sets. In the two-circuit tuner these disturbances are lessened to a considerable extent by loosening the amount of coupling between the primary and secondary coils.

47. The secondary coil *a*, Fig. 12, should have approximately the same inductance as the primary coil *c*. The variable condensers *b* and *d* may have a maximum capacity of .0005 microfarad for the higher frequencies. When receiving signals at lower frequencies the condensers should be larger. The detector tube, if not too free of gas, should be connected

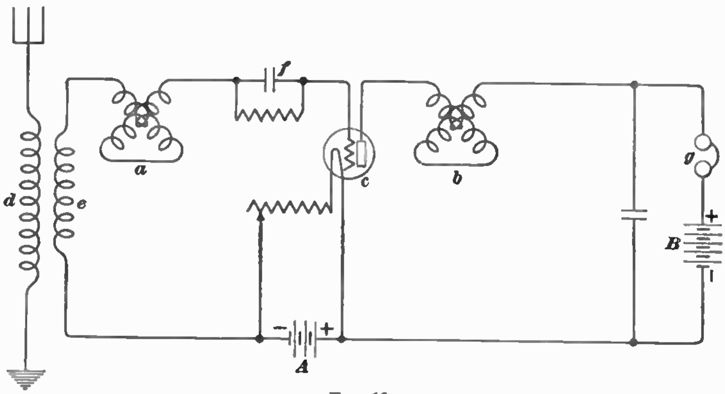


FIG. 13

in the manner shown, with the negative terminal of the *A* battery always connected to the grid lead. If a tube possessing a high vacuum is used, the positive terminal of the *A* battery would be connected to the grid if a grid condenser is used. Without a grid condenser, the negative terminal of the *A* battery should be connected to the grid. The feed-back coil, or tickler, *e* usually has a smaller number of turns than the secondary coil *a*, and the amount of energy so transferred to the grid circuit is regulated by the variable coupling between the two coils.

48. Three-Circuit Regenerative Set.—The three-circuit regenerative tuner, Fig. 13, derives its name from the fact that it has three tuned circuits. The first of these is the antenna circuit, the second is the grid circuit, and the third is the plate circuit. The grid and the plate circuits are tuned by means of the variometers *a* and *b*. Regeneration is obtained by means of the tuned plate circuit, acting through the internal capacity between the elements of the vacuum tube *c*. This circuit possesses all the advantages of the two-circuit regenerative receiver, and is even more selective. It is especially efficient in the reception of signals on the shorter wave-lengths.

49. The primary circuit including the inductance coil *d*, Fig. 13, may be untuned, as shown, or tuned by varying the inductance of the coil in steps of one or more turns. Sometimes a small capacity variable condenser, say .0005 microfarad, is included in the primary circuit for finer tuning. The secondary circuit includes the inductance coil *e*, the variometer *a*, the grid condenser *f*, all connected in series in the grid circuit of the vacuum tube *c*. The third, or the plate, circuit may be traced from the plate of the vacuum tube *c*, including the variometer *b*, the telephone receivers *g*, the *B* battery, the filament, and the electronic path through the tube.

The grid variometer *a* may be eliminated and a variable condenser placed across the inductance coil *e*. The inductance of the coil would have to be modified to correspond with the capacity of the shunt condenser so that a suitable frequency range could be covered with the latter combination.

ADDING COILS TO SET

50. A receiving set may work very well over a limited range of wave-length values, and, for maximum efficiency this condition should be obtained. Large coils have correspondingly large losses even when only a small part of the coil is active in the circuit. Sometimes it becomes desirable to be able to receive longer wave-length, or lower frequency, signals than those for which the set is designed. Provision is generally made in honeycomb-coil sets for using coils especially designed for various ranges of wave-lengths. It is then a simple matter to remove the old coils and substitute a set which will receive the desired signals.

51. Loading Single-Circuit Set.—A single-circuit receiving set essentially comprises a main tuning coil *a*, Fig. 11, and a plate feed-back coil *c* to make the set regenerative. The wave-length of the set may be raised by adding more inductance to the antenna coil *a*. This may be done by either winding more wire on the coil, so that the inductance effect of the main coil *a* is increased or by including another coil in series with the main coil. The wave-length range may also be increased by removing the series condenser *b* and connecting a condenser across either all or a part of the coil *a*. This condenser should have a capacity of about .00025 microfarad for most applications. A shunt condenser is not very satisfactory except where the wave-length change is reasonably small, say 50 per cent. increase.

The tickler coil *c* often has enough turns to produce regeneration on wave-lengths above those for which the set was designed. Adding more turns to the tickler coil is the most satisfactory procedure in case there are not enough on the coil. A small condenser, say .00025 microfarad or less, connected between the grid and the plate leads will generally give all the additional feed-back action that is necessary. It should be noted that the grid return is connected to the negative *A* battery terminal, which is proper when a grid condenser and leak are used on a so-called soft detector tube. When a grid condenser and leak are used with a hard tube, the grid return lead is connected to the positive terminal of the *A* battery.

52. Loading Three-Circuit Set.—The three-circuit set of Fig. 13 has three tuned coils or circuits. Coil *d* is the primary and is coupled to the secondary *e*, which is tuned by the variometer *a*. The plate circuit is tuned by the plate variometer *b*. The primary circuit may be tuned to longer wave-lengths by the addition of turns to the coil *d*, by including another coil in series with the coil *d*, or by connecting a condenser across the original coil *d*. The secondary may be tuned to longer wave-lengths very easily by placing a shunt condenser across the outside terminals of the coils *a* and *e*. The wave-length to which the plate circuit will tune may be increased by inserting an extra inductance coil in that circuit, or by connecting a .00025-microfarad condenser across the variometer.

USE OF COILS WITH CONDENSERS

53. Wave Traps.—It has been shown how a coil with a condenser across it may be tuned to any desired radio signal. This principle may be made use of where it is desired to tune out one or more interfering stations. One of the commonest methods of use is to couple such a combination, often called a *wave trap*, to a couple of turns of wire in the antenna circuit. The wave trap, as shown at *a* in Fig. 14, is then tuned to the frequency of the interfering station and absorbs some of the undesirable energy from the antenna circuit, thus reducing the interference in the receiving set connected at *b*. The wave trap has very little effect on signals to which it is not tuned.

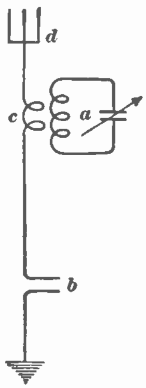


FIG. 14

The wave trap may also be connected directly in the antenna circuit between the points *c* and *d* in place of the two turns of wire. Here, as previously, the wave trap is tuned to the incoming undesired signal by varying the condenser until the interfering station is eliminated. When this condition obtains with this connection the circuit is tuned to form a very high impedance to the undesired signal and practically to keep the signal out of the receiving set. It is possible to use more than one wave trap when there is interference on several wave-lengths or frequencies.

54. Filters.—Electric *filters* are coil and condenser combinations so arranged as to pass certain desired current frequencies and oppose or retard currents of other frequencies. If the filter is designed to pass relatively high-frequency currents it is called a *high-pass* filter, while if it passes lower frequency currents it is known as a *low-pass* filter. The basic principles of all filters are that a condenser offers the higher opposition to a relatively low-frequency current, while an inductance offers its greater opposition when the frequency of the current is relatively high.

55. The elementary arrangement of a **high-pass filter** is shown in Fig. 15 with the condensers *a*, *b*, *c*, *d*, *e*, *f*, and *g* in series in one line. The inductance coils *h*, *i*, *j*, *k*, *l*, and *m* are all connected in parallel across the main circuit wires carrying both the desired and undesired currents which will be considered at a certain instant to approach from the left. A low-frequency current will be considerably opposed by the

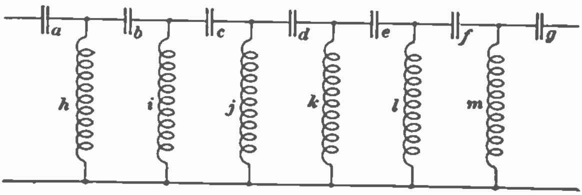


FIG. 15

condensers directly in its path while the higher-frequency currents can readily pass through the condeners. However, the parallel inductances provide a convenient return path for the low-frequency currents without forming such a good shunt path for the higher-frequency currents. This combination of inductances and condensers serves admirably to pass high-frequency currents and by-pass those of relatively low frequencies.

56. About six sets of inductances and condensers, as shown in Fig. 15, are necessary to secure best filtering action, although some effect will be produced by even one inductance-condenser combination. The inductance coils are all identical, and so are the condensers except that the end ones are one-half as large as the others.

The value below which signals will be eliminated or weakened is known as the *cut-off frequency* and is denoted as f in the following formula

$$f = \frac{1}{4\pi\sqrt{LC}}$$

in which f = frequency, in cycles per second;
π = 3.1416 (π Greek letter pronounced *pi*);
L = inductance of a coil, in henrys;
C = capacity of any one of the condensers between the end sections, in farads.

The capacity of a condenser to combine with a .005 henry inductance coil to cut off frequencies below 800 cycles per second may be calculated from the formula, as follows:

$$800 = \frac{1}{4\pi\sqrt{.005 \times C}}$$

The capacity as calculated is .000002 farad. It is possible to use other condenser and inductance combinations to filter out this same frequency, however.

57. The **low-pass filter** of Fig. 16 has the inductance coils *a*, *b*, *c*, *d*, and *e* connected in series in the main line, while the condensers *f*, *g*, *h*, and *i* are connected in parallel across the line. The inductance coils tend to impede the passage of

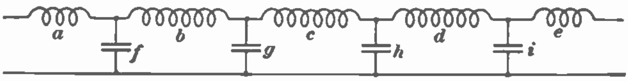


FIG. 16

high-frequency currents while passing relatively low-frequency currents with little opposition. At the same time the high-frequency currents find an easy return path through the shunt condensers which have little effect on the lower-frequency currents. These devices therefore combine to pass low-frequency currents while by-passing those of relatively higher frequencies.

The cut-off frequency may be found by the use of formula

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

in which f = frequency, in cycles per second, above which currents will be eliminated or at least greatly reduced;

L = inductance, in henrys, of each coil between the end ones, which are one-half size;

C = capacity, in farads, of any one of the condensers, which are in this case of equal value.

The inductance coil to combine with a condenser of .00003 farad to eliminate frequencies above 100 cycles per second can be found by an application of the formula

$$100=\frac{1}{3.1416\sqrt{L\times .00003}}$$

$$L=.3 \text{ henry}$$

Other combinations of capacity and inductance would have the same cut-off action, but it is desirable to use a coil with a rather small number of turns so its resistance will not be too high.

58. For choking out 60-cycle alternating currents, it is possible to obtain a greater inductive effect from the coil by winding the turns on an iron core. The formulas apply just as well to this type of inductance as to any other, and may be used in calculating the condenser and coil combination to eliminate a 60-cycle hum. A filter made up of one or two coil and condenser sections does not have a very sharp cut-off frequency, but is often more convenient than a larger one, and serves the purpose very well.

AUXILIARY RADIO APPARATUS

VARIOCOUPLERS

59. Variocouplers are essential tuning elements of some radio sets, and are made in various styles. In Fig. 17 (*a*) is shown one type of variocoupler of very good design and construction. The coil *a* is securely wound on a piece of composition tubing. Single-turn tuning taps are taken off

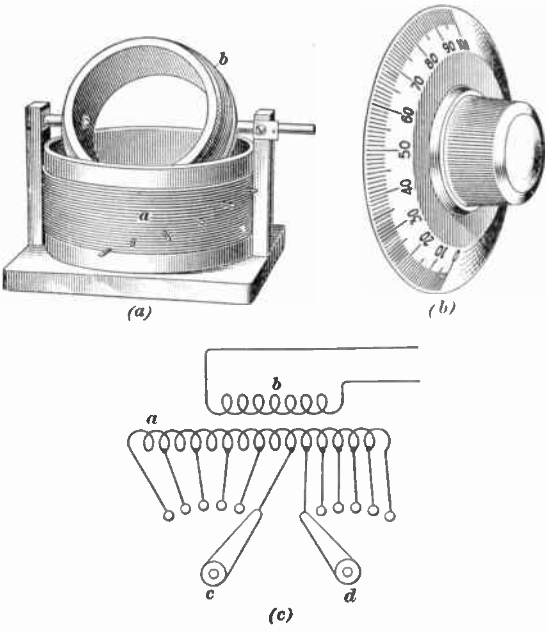


FIG. 17

the coil on the side not shown, although such practice is not especially necessary. It is important, when selecting a variocoupler, to obtain one with turns enough on both the primary and secondary windings to reach the desired wave-length range. The material on which the wire is wound should be of good quality and of a kind that will not cause unnecessary losses. The secondary coil *b* is mounted so that it may be rotated to give either close or loose coupling with the primary coil. The shaft projects at one end for mounting a dial.

The usual type of dial, including a knob for turning the shaft of a variocoupler, is shown in Fig. 17 (*b*). The variocoupler, view (*a*), when mounted in a set, has the extension of the shaft projecting on the opposite side of the panel. The dial, view (*b*), is then placed on the portion of the shaft extending from the front panel and fastened to the shaft. By then turning the dial, the rotor *b*, view (*a*), is rotated within the stationary coil *a*.

60. In the usual radio circuits the variocoupler is drawn in the manner indicated in Fig. 17 (*c*). The stationary coil and the rotor are shown at *a* and *b*, respectively. The stationary coil has its taps connected to contact points. By turning the switch arms *c* and *d*, any number of turns may be connected in the circuit including the stationary winding of the variocoupler. The secondary *b* of the variocoupler serves as the secondary in the usual receiving circuits, or it may be used as a feed-back, or tickler, coil in single-circuit regenerative receivers. For example, in Fig. 10 a variocoupler might be used for the coils *b* and *c*, in which case it would act like the usual radio-frequency transformer. In Fig. 11, the use of a variocoupler necessitates the use of the stator as an autotransformer, while the rotor can well assume the role of the tickler coil *c*.

VARIOMETERS

61. A variometer consists essentially of two coils, one stationary and one capable of being rotated within the stationary coil, with both coils connected in series. When the lines of force of one of the coils coincide with the direction of the lines of force of the other coil, maximum inductance obtains. When the rotor of the variometer is turned in the opposite direction so that the lines of force of the one coil oppose those of the other coil, minimum inductance obtains. Between these two limits a continuous variation of inductance is obtained as the relative position of the coils is gradually changed.

One type of commercial variometer is shown in Fig. 18. The stationary coil is mounted within the frame *a* and the rotor coil *b* is wound on a composition frame. In this type of variometer the distributed capacity of the coils is reduced by the ribs which hold the wire away from the adjacent masses of supporting material.

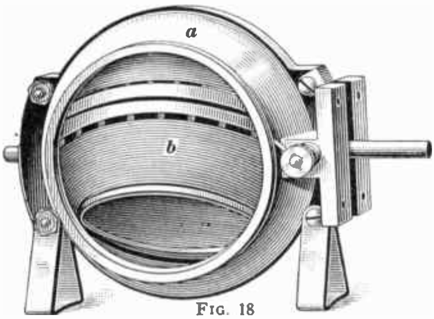


FIG. 18

A variometer may be used wherever a continuous variation of inductance is required. It is of great advantage in a three-circuit tuner, as has been shown in Fig. 13, where one variometer is used in the grid circuit and another in the plate circuit.

MOUNTING SPIDER-WEB COILS

62. In Fig. 19 is shown one method of mounting three spider-web coils so as to obtain mutual induction between

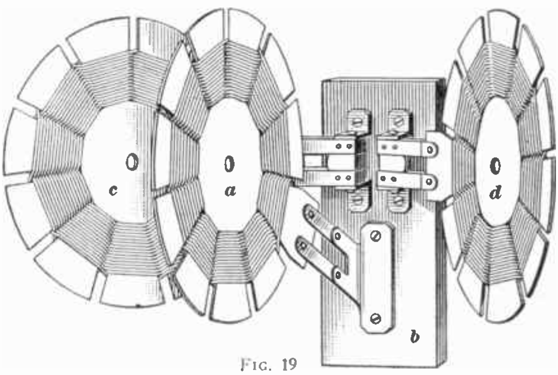


FIG. 19

them. The center coil *a* is mounted rigidly to the back board *b*, while the coils *c* and *d* are fastened to hinged supports and may be swung towards or away from the coil *a*. Three such coils may be used in the tuner shown in Fig. 12, where the coil *c*, Fig. 19, would serve as the primary, the coil *a* as the secondary, and the coil *d* as a tickler. Honeycomb coils are mounted in a similar manner; different supports are required for these coils, but the inductive relation is obtained by placing the coils side by side.

Where only two coils are required as in Figs. 10 and 11, one of the coils of Fig. 19 need not be used, or a mounting may be obtained for two coils only.

FIXED CONDENSERS

63. Fixed condensers of the type used in receiving sets are made in a variety of forms. One type of such condensers is shown in Fig. 20. This condenser is provided with soldering lugs *a* and *b* to which the proper conductors may be securely and permanently fastened.

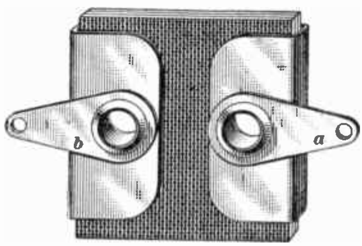


FIG. 20

Fixed condensers are used in various circuits of radio receiving sets. Grid condensers are usually of fixed capacity ranging from .00025 to .0005 microfarad capacity. Telephone condensers have a capacity of approximately .002 microfarad.

Condensers, for best operation, should have low electrical losses. Both the design and the construction of the condenser should be taken into consideration when one or more are required in a set.

GRID LEAKS

64. Grid leaks are made in many types and forms. The soft or gassy tube does not require a grid leak, while all the hard or high-vacuum tubes require grid-leak resistances for best operation. Occasionally a high-resistance leakage path inside the set obviates the necessity for a grid leak. The resistance of a grid-leak path may be from 500,000 to 9,000,000 ohms. One style of fixed grid leak is shown in Fig. 21, and is representative of many others of the same general type of construction. These may be purchased in a wide variety of resistance values. Quite satisfactory grid leaks may be made by impregnating Manila paper with India ink. Pins stuck into narrow strips of this paper may be used as terminals for connection to the desired part of the circuit. Variable grid leaks may be used where special results are desired. Their effect will be most noticeable when adjusting the set to weak signals.

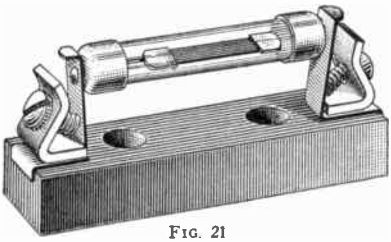


FIG. 21

RHEOSTATS

65. A **rheostat** is practically always used to control the filament current to the electron tubes. Many are of the general appearance of the one illustrated by Fig. 22, in which the resistance wire *a* is mounted on some type of insulating material. A pointer *b* moves over the resistance wire so as to include all or any desired part of the wire between the two main terminals. Rheostats are often designed so they may be mounted on the back of a panel with the shaft carrying the pointer extended through and controlled by a knob or dial. Some types have an auxiliary device of some kind to give a vernier control, or an arrangement for securing minute continuous variation of the resistance. The vernier generally has a resistance variation about equivalent to that between one or two turns of wire in the

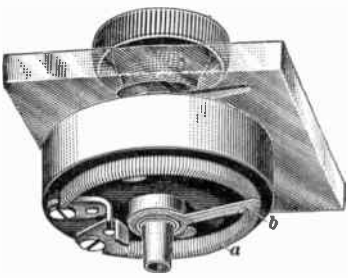


FIG. 22

main resistance unit, and is used for securing adjustments finer than those provided by the main pointer. A large wire is used when the rheostat will control the current from high-current tubes, while a much smaller size will give better control on the low-current types of electron tubes.

Rheostats with the resistance made of carbon have been very successfully used. The carbon may be in the form of disks or of powder, or it may be combined with some other material for handier manipulation. A component part of the rheostat is a device, usually a machine screw, to increase or decrease the pressure between the carbon particles and thus lower or raise the resistance, respectively.

POTENTIOMETERS

66. A **potentiometer** in its true sense is an instrument or an arrangement of circuits for measuring voltages. In radio work the word potentiometer has been applied to a device by means of which a given voltage may be divided and applied to certain circuits. The potentiometer consists essentially of a resistance, which may be varied in a similar manner as the resistance of a rheostat. The potentiometer resistance is connected across the terminals of a battery. A circuit is then obtained by connecting one end of a conductor to either the positive or the negative terminal of the battery, and the other end of the conductor to the slider of the potentiometer.

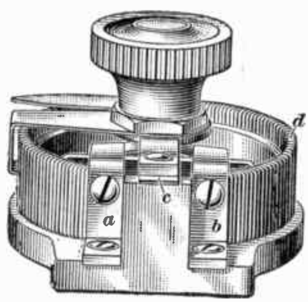


FIG. 23

A potentiometer, when used, is generally connected across the filament battery to give the desired bias on the grid. With soft or gassy tubes the potentiometer was generally connected so as to vary the plate voltage since the plate potential was inherently critical with that type of tube.

The main function of a potentiometer is to provide adjustable voltages by utilizing the voltage drop in a resistance wire.

If too small in size this wire is not mechanically strong, while if too large the energy taken from the *A* battery is excessive. At any rate it is well to include a switch in the circuit so as to disconnect the potentiometer when the set is not in use. In Fig. 23 is shown one type of potentiometer with the two battery terminals at *a* and *b* and the variable sliding contact connected to the terminal *c*. The resistance wire is shown at *d*.

SOCKETS

67. Electron-tube **sockets** are made in many styles and designs by different manufacturers. They consist essentially of a shell to hold the tube in position, and four springs in the base to make contact with the four pins in the base of the tube. The shell is often of metal, although various compounds, such as bakelite, have been used. For some types of tubes there is a slot in the side of the shell which engages a pin in the side of the tube base to hold the tube in position. Fig. 24 shows the shell at *a* and the slot at *b*. The base springs *c* are extended inwardly so as to make good contact with the tube base pins. Sometimes the spring presses on the side of the pin while in other types of construction contact is made with the end of the pin. The outer end of the spring has a small screw for holding connection wires. With considerable use the contact springs are apt to become dirty, and cause a poor connection. The springs are also liable to become sprung down with continued use so they do not make firm contact with the tube. It is important to see that the contact springs are kept clean and bent up into their normal position.

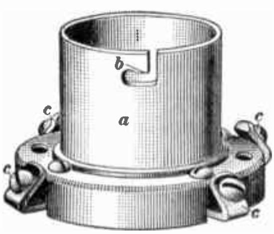


FIG. 24

Special types of tubes have brought new types of electron-tube bases into the field. Very often it is desirable to try these tubes in existing sets equipped with sockets to fit the older style bases. *Adapters* have been devised which enable the tubes with special bases to be used in the older-style sockets.

LOUD SPEAKERS

68. Purpose of Loud Speakers.—Loud speakers are special types of receivers designed to reproduce radio telephone or telegraph signals with considerable intensity and without distortion. While a horn attached to head telephone receivers of standard design will often give good results, the best reproduction is generally secured by loud-speaker elements and horns of special design.

The loud speaker ordinarily takes a stronger signal to give loud sounds than does a pair of head phones. The diaphragm must, therefore, vibrate through a greater distance and must be free to do so without touching the magnet pole pieces. Some loud speakers have a separate armature or coil in the strong magnetic field, and this armature is connected mechanically with the diaphragm.

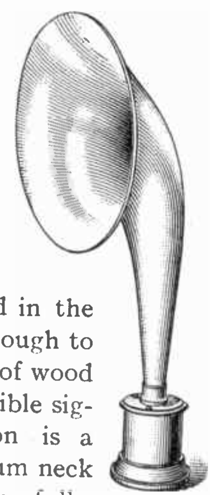


Fig. 25

69. Horn of Loud Speaker.—A complete loud speaker is shown in Fig. 25 with the receiver unit of special design enclosed in the base. The protective base is also heavy enough to hold the fiber horn upright. A horn made of wood pulp or fiber gives a very good tone to audible signals. Another good style of construction is a wooden bell or open end with a cast-aluminum neck leading to the loud speaker unit. Some carefully designed all-metallic horns have given very good results. Much depends upon the shape of the horn and upon the size of the openings at the small and large ends. A small horn is apt to emphasize high notes, while one too large is liable to accentuate the low notes and give an unpleasant tone to high-pitched voices or music. The finish of a horn is also important and a rather rough surface is desirable, especially on the inside of the horn.

70. Electrodynamic Reproducer.—The actual operating mechanism varies considerably in style and principle with the loud-speaker equipment made by various manufacturers. The essential parts of one type of reproducer are shown in Fig. 26. The wires *a* and *b* connect with a battery that sends current through the coil *c* to form a strong electromagnetic field. The switch *d* opens this circuit when the unit is not in use. The electromagnetic field is produced between the pole *e*, which is in the form of a ring, and the small circular pole *f*. The coil of wire *g* is coupled mechanically at point *h* with the diaphragm, which is mounted near the base or neck of the horn. The outer edge of the diaphragm is solidly mounted and the movement of the center portion through the mechanical coupling from coil *g* converts the electrical energy received by the coil *g* into audible signals from the horn. The diaphragm sometimes has concentric circular corrugations to make it equally responsive to signals of all frequencies. Some loud speakers have a transformer as shown with the coils *i* and *j* so as to operate from electron-tube circuits by electromagnetic induction. Others are designed to connect directly in the circuits of standard receiving sets.

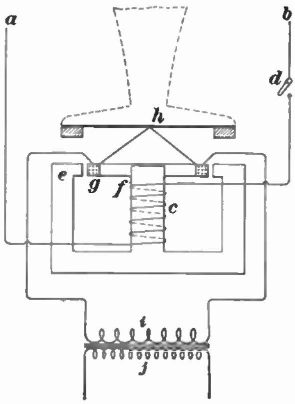


FIG. 26

71. Relay-Type Reproducer.—The relay-type reproducer receives its name from the fact that its operation is the same as that of a polarized relay that is so extensively used in line telegraphy. As indicated in Fig. 27, the reproducer consists essentially of four electromagnets *a*, *b*, *c*, and *d*, which are mounted in pairs on the opposite poles of a permanent magnet *e*. A

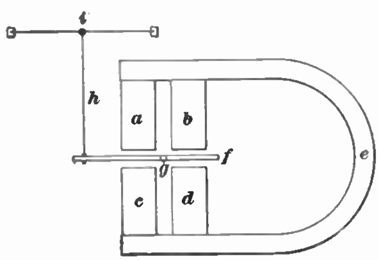


FIG. 27

vibrating armature *f*, pivoted at *g*, has one of its ends connected through a small rod *h* to the loud-speaker diaphragm *i*. The electromagnets are so connected that the armature is simultaneously attracted by two of them and repelled by the other two poles. Thus, the electromagnets *a* and *d* act in unison, and also the electromagnets *b* and *c*. Variations of current in the coils of the electromagnets cause corresponding variations of attraction on the armature *f*. The armature, in rocking on its pivot *g*, acts on the diaphragm *i* through the rod. Every movement of the armature is, therefore, conveyed to the diaphragm, which translates into sound all the electrical variations within the coils of the electromagnets.

72. Balanced-Armature Type Reproducer.—The basic actions of the balanced-armature type reproducer resemble closely those of the reproducer just described. In the balanced-armature type, however, the electrical energy, instead of modifying the attraction of the permanent magnet, is made to vary the magnetism of the armature that rocks between the poles of a permanent magnet. As shown in Fig. 28, the armature *a* carries a coil that is connected in series with the secondary of the step-down transformer *b*. The permanent magnet *c* has semicircular pole extensions, each of which is near one of the armature ends. The two extensions of each pole piece have the same polarity as the pole to which they are connected, the polarities being clearly indicated in the figure.

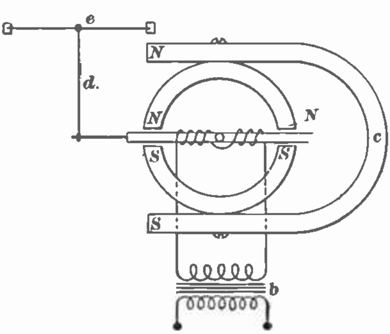


FIG. 28

73. Current through the armature coil of the reproducer, shown in Fig. 28, in one direction will give the ends of the armature certain defined polarities. If, for example, the left-hand end of the armature is made a north pole, the opposite end will be a south pole, and by the law of magnetic attraction, the left-hand end of the armature will be attracted by the lower south pole of the permanent magnet, while the opposite south pole of the armature will be attracted by the upper north pole of the permanent magnet. When the current in the armature coil reverses in direction, the armature will also swing in the opposite direction. Variations in the strength of the current will produce variations of attraction between the armature and the poles of the permanent magnet. As the armature is connected through a rod *d* to a diaphragm *e*, all the movements of the armature are conveyed to the diaphragm. Hence, the diaphragm will not only register the alternations of current in the armature coil, but it will also reproduce faithfully all the variations in amplitude of the current in each direction. The primary winding of the step-down transformer *b* is connected in the plate circuit of the last amplifier tube. The reason for using a step-down transformer is to obtain a certain balance between the plate circuit of the amplifier tube and the primary of the transformer, as well as between the armature coil of the reproducer and the secondary of the transformer. In this manner maximum efficiency is attained.

ASSEMBLY OF RECEIVING SETS

ARRANGEMENT OF PARTS

74. The various parts entering into the construction of a receiving set should be properly arranged and neatly mounted on a suitable panel. A suitable arrangement of parts for a single-circuit tuner is shown in Fig. 29 (*a*). The various apparatus is shown as it appears when the set is viewed from the top.

The instruments by means of which the set is adjusted are mounted on the panel *a*. The panel is of some insulating material like hard rubber or bakelite, cut to the required size. The first device that may be seen on the left of the panel is the binding post *b*. Two binding posts are actually on that side, but due to the position of the panel only one may be seen in the illustration. The next in line is the variable condenser *c*. It is fastened to the panel by means of flat- or oval-head machine screws, with the shaft of the rotary plates extending on the opposite side of the panel. On the extension of the shaft is mounted the dial and rigidly fastened to the shaft. By turning the dial, the movable plates of the condenser are also turned and the capacity of the condenser is varied.

Next to the condenser is the variocoupler *e*. The rotor of the variocoupler is mounted on a shaft, one end of which

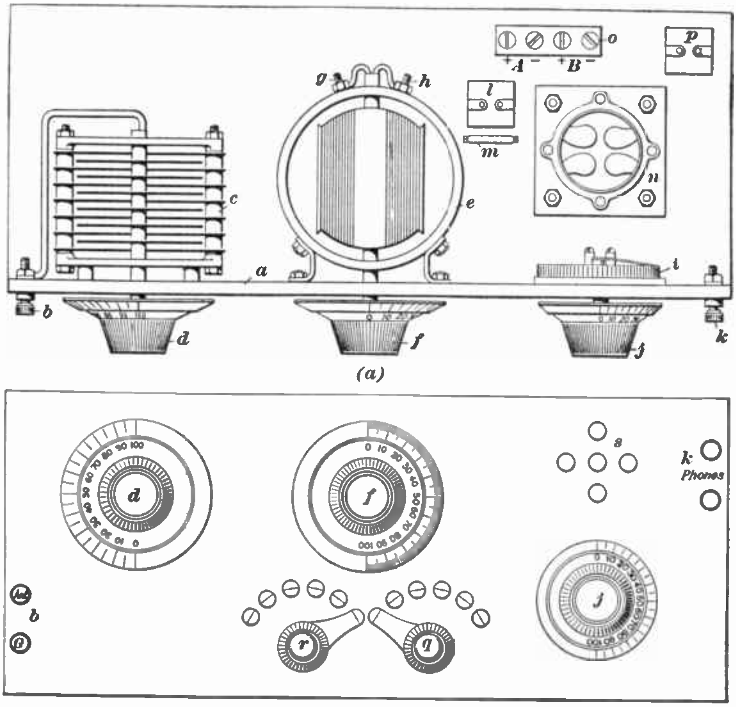


FIG. 29

extends to the front of the panel and carries a regulating dial *f*. The other end of the shaft is hollow and through it are brought out the terminals of the rotor winding and fastened to the binding posts *g* and *h*.

The next device on the panel is the rheostat *i*, which also has a regulating dial *j* on the outside of the panel. The rheostat is provided with two binding posts to which the proper conductors are connected.

The telephone binding posts are on the right-hand side of the panel, and one of them may be seen at *k*.

The grid condenser *l*, Fig. 29 (*a*), the grid leak *m*, the tube socket *n*, the battery binding posts *o*, and the condenser *p* that is bridged across the telephone receivers and the *B* battery, are all mounted on the base board of the receiving set. These parts should be so arranged that the wire connections between them and the parts mounted on the panel are as short as possible. Frequently the cabinet that houses the receiver parts is made large enough to contain the batteries required in the set; this is especially true when tubes are used that require a small current for properly lighting the filament.

Usually a separate base made of the same material as the panel is provided for mounting the grid condenser, socket, etc., in the set. This base need be only large enough to accommodate the necessary devices.

75. The front of the panel will have the general appearance of Fig. 29 (*b*). The condenser, variocoupler, and rheostat dials are shown at *d*, *f*, and *j*, respectively. The antenna and ground binding posts are at *b*, and the binding posts to which the telephone receiver cords are fastened are at *k*. Two switch arms *q* and *r*, provided with suitable knobs, are also mounted on the panel. When these switch arms are turned, they will come successively in contact with the switch points that are connected to the various turns of the stationary winding of the varicoupler. Peep holes are provided at *s* so that, without opening the top of the cabinet, the operator may readily see that the filament of the vacuum tube lights when the rheostat is turned.

WIRING RECEIVING SET

76. Necessity of Wiring Diagram.—When all the parts required for a given type of set have been properly mounted in position, the wiring of the set may be started. The experimenter should have at hand a good wiring diagram or at least a circuit diagram, which, for the set under consideration, may be the one shown in Fig. 30. A comparatively simple circuit has been chosen to exemplify the wiring of a receiving set. When a more complicated circuit is used, the procedure is much the same. A list is made of the devices necessary in the receiving set, and these devices then mounted on a suitable panel in the same manner as those of the simpler set. More

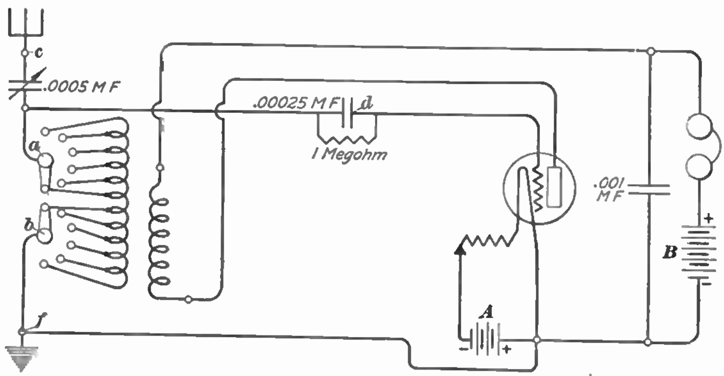


FIG. 30

care will be required in assembling a complicated set, for more devices will be used, and their arrangement will frequently have an appreciable effect on the incoming signals. Mutual induction between conductors and coils has a detrimental effect on the selectivity of the set, and in all cases, care should be taken to prevent it as much as possible. Wiring diagrams usually show the positions of the various devices and also the paths of the conductors connecting the necessary parts. In circuit diagrams such a provision is not made, hence it is necessary for the installer to keep in mind the causes that produce undesirable results, and arrange his set accordingly.

77. Wire Connections.—The first device to be wired is the variocoupler. The more common types of variocouplers have the stator winding tapped at each definite number of turns. By means of short lengths of wire, connections are made from the taps to the switch contact-point terminals in the rear of the panel. One end of each wire is soldered to a tap on the variocoupler, and the other end is fastened either by soldering or by screws to the inside terminal of a contact point. One set of switch points, say those of the arm *a*, Fig. 30, are each connected to several turns of the variocoupler, while the switch points of the switch arm *b* are each connected to single turns. The switch arms *a* and *b*, Fig. 30, correspond to the arms *r* and *q*, Fig. 29 (*b*). The wire used for connecting the taps on the variocoupler may be of the same size as the winding itself with similar insulation, or a larger insulated wire may be used. Care should be taken that the individual wires do not come in bare contact, for in that way the inductance of the turns short-circuited by the contact would be destroyed.

78. The rest of the set may be wired with No. 14 B. & S. gauge copper conductor, but preferaby with regular bus-wire. If bare wire is used, a protective sleeve should be placed over the conductors, especially in places where there is the possibility of the conductors coming in contact.

Starting from the antenna connection *c*, Fig. 30, a connection is made to the movable plate terminal on the condenser. The terminal for the stator plates has two connections; one connection extends to the grid condenser and leak *d*, and the other connection to the switch arm *a*. The ground terminal *f* is common to the switch arm *b* and the negative terminal of the *B* battery. The terminals *c* and *f*, Fig. 30, correspond to the terminals shown at *b*, Fig. 29 (*a*) and (*b*). From the other side of the grid condenser *d*, Fig. 30, a connection is made to the grid terminal on the vacuum-tube socket. The connecting wires should be bent neatly in the manner indicated in Fig. 29 (*a*) for the conductor connecting the antenna terminal *b* and the rotary plates of the condenser *c*.

79. All the connections should be firmly made. When a connection is made to a binding post, the portion of the conductor that is clamped between the binding screws should be well scraped and made fast to the binding post. The contact surface of the wire and of the binding post should be as large as possible.

Soldered connections, when properly made, are usually preferred because the resistance of the conductors is thereby reduced. The two conductors that are to be soldered must have a clean surface. The hot soldering copper is applied to the joint and a small quantity of solder deposited. The solder should be of the kind with a rosin core, the rosin acting as the flux. Fluxes other than rosin should be avoided. The tip of the soldering copper should be well tinned, and when soldering, the copper should be hot enough to melt the solder as soon as applied. An improperly heated soldering copper may melt the solder if in contact with it long enough, but the resulting connection will be poor both as to appearance and as to conductivity.

80. The single circuit regenerative receiver is not recommended for thickly populated areas on account of the interference it produces when regenerating. In isolated country districts it may be used to advantage, for there no other receivers will be near enough to be affected by it.

In thickly populated areas, especially where several receiving sets are in close proximity, the use of regenerative receiving sets should be avoided, if not prohibited. Radio frequency amplification may be used for increasing the receiving range, and if a regenerative detector is used it should be preceded by at least one stage of radio-frequency amplification.

RADIO-FREQUENCY AMPLIFICATION

APPARATUS AND CIRCUITS

INTRODUCTION

1. Nature of Radio Signals.—Radio signals intercepted by a receiving station induce high-frequency voltages in the receiving antenna system. The resultant current in the antenna circuit, normally, has all the characteristics of the original current in the transmitting system with the one main exception, that of value. The energy set up at the receiving station is very small compared with the energy at the transmitting station. For a given amount of energy at the transmitting station, the received energy will vary inversely as the square of the distance. It may, therefore, be deduced that the received signal carries only a small portion of the energy that was used to send it out. With suitable apparatus, however, this received energy may be utilized directly or indirectly to produce audible or visible signals.

2. Necessity of Radio-Frequency Amplification.—The intensity of the received signal is in many cases sufficient to be detected with a suitable detector-tube receiving set, or even with a crystal set. Frequently, however, the signal is so faint that it cannot be converted directly, so as to be perceptible to the senses. The distance between the transmitting and the receiving stations may be too great; the amount of energy used may be insufficient to carry the signal to its destination with any degree of satisfaction; atmospheric and other disturbances may prevail; all these factors are responsible for the intensity of the received signal.

To give a weak signal the intensity necessary to operate a detector tube, use is made of radio-frequency amplification. Radio-frequency amplification is, therefore, a system or means of increasing the amplitude of a received signal at its original radio frequency or at some other radio frequency to which the signal may have been converted.

3. Advantages of Radio-Frequency Amplification.—Radio-frequency amplification finds its greatest usefulness in the reception of extremely weak signals. A single stage of radio-frequency amplification is often used in connection with a standard receiving set to give additional signal strength, or receiving range, or both. Excellent results have been obtained by the addition of one amplifier tube with its auxiliary apparatus, coupled to a common regenerative receiver.

There is a high degree of selectivity obtained in many types of radio-frequency amplifiers. This is often desirable as it permits of tuning in only the desired station, and that through considerable local interference. Such selectivity, however, is not limited strictly to radio-frequency amplifiers.

It is claimed that radio-frequency amplifier sets do not radiate any energy from the receiving antenna. If the set is properly adjusted, such is undoubtedly true, but that is not always the case. Radio-frequency amplifiers do generally operate with a minimum of interference with neighboring sets.

Radio-frequency amplification is usually employed with sets using loop, or coil, aerials. The signal intercepted with a loop aerial is, at best, very weak. By taking advantage of radio-frequency amplification, the signal intensity may be increased without detriment to the beneficial effects of loop reception.

RADIO-FREQUENCY APPARATUS

TUNING COILS AND CONDENSERS

4. The reception of radio signals presupposes the use of a suitable antenna with the proper tuning coils and condensers. The antenna circuit should be adjusted so as to be in resonance with the frequency of the incoming signal. All the tuning or adjusting is done by means of inductance coils and condensers.

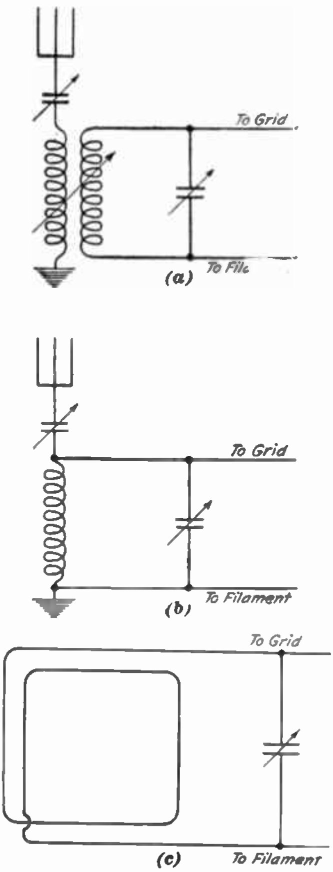


FIG. 1

Three tuning arrangements are indicated in Fig. 1. In view (*a*) is shown an arrangement using two coils and two condensers. The antenna, or the primary, circuit is tuned by means of the condenser or the tuning coil, or both. The secondary circuit usually has a fixed inductance coil, the tuning being accomplished by means of the variable condenser. The two coils may be the stator and the rotor of a variocoupler, or two honeycomb or spider-web coils with the required number of turns. The two extensions from the secondary winding are connected to the grid and filament terminals of the amplifier tube.

In view (*b*) only one coil is shown. Any suitable inductance coil may be used for this purpose provided that its inductance is satisfactory for the desired frequency. A honeycomb coil, a spider-web coil, a variometer, or any other type of coil or fixed or variable inductance may be used for this purpose.

A loop antenna, view (*c*), is connected to the grid and filament terminals of the amplifier tube. This is the simplest arrangement of all. A loop with a sufficient number of turns is shunted by a variable condenser, and its terminals are connected directly to the grid and filament terminals of the amplifier.

AMPLIFIER TUBES

5. The frequencies of the currents to be amplified by radio-frequency means are so exceptionally high that special apparatus is desirable for this purpose. The operation of a radio-frequency set is often greatly affected by the tube. Although the characteristics of the various types of commercial tubes do not vary greatly, some sets have been found to work well with certain types of tubes and not at all satisfactory with other types. The tubes that require little energy have not generally given as satisfactory service as those using more energy.

There is an appreciable electrical capacity between the elements of the tubes that is important in radio-frequency work. In considering the grid and plate circuits it must be realized that there is a fairly large capacity effect between the grid and plate elements. This capacity acts as a coupling condenser. Even if this capacity is of the order of a few micro-microfarads, it provides a path of relatively low resistance to radio-frequency currents. In fact, unless special precautions are taken, the tube capacity will actually act as a feed-back from the plate to the grid circuit and cause the set to oscillate. This oscillation at radio frequency is above audibility, so does not cause any audible sound in the set. Very often a set will oscillate at radio frequency, and prevent the reception of signals while making no indication in the telephone receivers.

6. It is desirable that the radio-frequency amplifier tubes be so designed that the capacity effect between the elements of the tube will be negligible. As a matter of fact most tubes designed to have exceptionally low capacities between elements also have inherently inferior electrical characteristics. The spacing of the grid and plate leads in the tube is also important, but can only be controlled in manufacture.

It is important that the wiring of the set be done so as to eliminate undesirable coupling effects between various parts of the circuit. This is especially true of the grid and plate circuits carrying the high-frequency current as it is very easy to get enough coupling to set up oscillations. It must be remembered that at radio frequencies even a small coupling capacity will act as a feed-back between the elements so joined, due to the low impedance offered to radio-frequency currents by even relatively small condensers.

BATTERIES

7. The batteries required for an amplifier set are the filament battery, the plate battery, and sometimes a grid battery. The size and type of filament, or *A*, battery to use depend on the type of tubes that are used. The *A*-battery voltage for the commercial radio-frequency amplifier tubes varies from 1½ to 6 volts, and the current from .06 to 1 ampere. A tube requiring .25 ampere at a pressure of 1.1 volts can be operated satisfactorily with one ordinary dry cell having the desired voltage. On the other hand, when a larger current and voltage are required it is more economical to use a storage battery.

The plate, or *B*, battery is usually a series of dry cells so arranged as to obtain the required voltage. Commercial *B* batteries are made of small dry cells neatly mounted in a box and sealed, with the positive and negative terminals extending outwards. Storage *B* batteries are also used to a considerable extent. The *B*-battery voltage is seldom less than 45, and does not usually exceed 90 volts.

The grid, or *C*, battery imposes a negative potential on the grid of the amplifier tube. When a plate voltage of 45 or less is used, the negative drop from the *A* battery is sufficient to obtain the necessary negative bias on the grid. With a plate voltage of 60 volts, a *C* battery of from 1 to 3 volts should be used; 80 volts on the plate requires 3 to 4 volts, on the grid; 90 to 100 volts on the plate requires 5 to 6 volts on the grid.

The grid battery is made up of several flash-light cells and connected in the grid circuit with the negative terminal of the *C* battery nearest the grid, and the positive terminal nearest the filament.

The proper grid bias can often be obtained by means of a potentiometer connected across the *A* battery, as indicated in most of the figures in this Section. This arrangement permits of adjusting the grid voltage while the set is in operation.

INTER-STAGE COUPLING

8. Connection Between Successive Stages.—When one or more stages of radio-frequency amplification are employed, some means must be provided to transfer the amplified radio-frequency signal from one stage to the next, and finally to the detector circuit. The most common form of coupling is the radio-frequency transformer, although any suitable inductance coil or resistance may be used to obtain this effect.

9. Radio-Frequency Transformers.—Commercial radio-frequency transformers are of several types. One distinguishing classification may be made by considering them from the standpoint of the cores, namely, air-core and iron-core transformers. These may again be classified as *fixed* and *variable.* The fixed transformer is so constructed that it will transfer the energy from one radio-frequency circuit to another with a fair degree of satisfaction over a considerable range of wave-lengths. The variable radio-frequency transformer may be adjusted for any desired wave-length, or series of wave-lengths.

10. Air-core radio-frequency transformers may be considered as all those that have an air core or some other non-magnetic core. These transformers consist essentially of two separate coils coupled to each other. The energy from one coil to the other is transferred through the air by electromagnetic induction. The step-up ratio of the number of turns in the primary to the number of turns in the secondary is usually low, that is, from 1 to 3, or less, as the circuits are not any too stable.

The fixed type of radio-frequency transformer is commercially made in very compact form. Essentially, however, it does not differ from the transformers wound on paper or composition tubes with the two windings either adjacent or over each other. The inductance and coupling of the coils in this type of transformer are fixed. The wave-length, or frequency, range of these transformers may be varied by shunting them with variable condensers. The wave-length range of air-core transformers may also be varied by taking taps off the windings and connecting the required number of turns in the circuit.

To reduce the capacity between the two windings of an air-core transformer they are wound of very fine wire, and sometimes spaced a short distance apart, although the coupling may be somewhat reduced thereby. The windings may be made of wire possessing considerable resistance in order to tend to keep the set from oscillating. This resistance also broadens the band of wave-lengths over which the transformer will amplify. The windings are sometimes made of very fine wire, say No. 40 to No. 44 B. & S. gauge, in order to reduce the distributed capacity of the transformer. This distributed capacity is the condenser effect between adjacent turns and adjacent layers and may be great enough to affect adversely the wave-length of the transformer.

11. The **design of radio-frequency transformers** is dependent to a large extent upon experience with such work. In general the home-made radio-frequency transformers are not so good as those made by experienced and reliable manufacturers. However, it is often of interest to note the effect of the size of wire, the number of turns, the spacing of turns, etc., as these and many other factors certainly play a vital part in the construction of a radio-frequency transformer.

Air-core radio-frequency transformers are very easy to construct and are satisfactory to experiment with. A convenient size and style of bobbin for such work is shown in Fig. 2. The dimensions in inches are given on the figure, but may be altered as conditions demand. The bobbin should be made of a high-grade insulating material, as hard rubber or some of the prepared materials. The bobbin could be mounted on a support by placing a screw of non-magnetic material through the axis of the spool.

12. The following factors influence or affect the wave-length range of a radio-frequency transformer and each should be considered. The size of wire affects the range by its effect on the resistance of the transformer, or its opposition to radio-frequency currents. The size of the wire also largely determines the amount of distributed capacity effective between adjacent turns of the coils, and to some extent the capacity between the primary and secondary windings. Both the thickness of and kind of insulating material on the wire have considerable influence on the distributed capacity of the coil, which capacity acts as a shunt to limit the wave-length range of the transformer. The number of turns is of utmost importance in determining the wave-length range of the transformer, and the number should be determined by trial. The number of turns on the primary and secondary affects the various inherent capacities, but this should be considered as of secondary importance to the main coupling features of the transformer. One to one ratio air-core radio-frequency transformers are the easier to construct and the most used, since little gain is ordinarily secured by a higher turn ratio. The capacity between the windings is directly dependent upon the distance between the primary and the secondary coils. The wave-length of the transformer is so dependent on this coupling capacity that the best amplification is often secured on another wave-length than formerly, if the distance between the coils is changed.

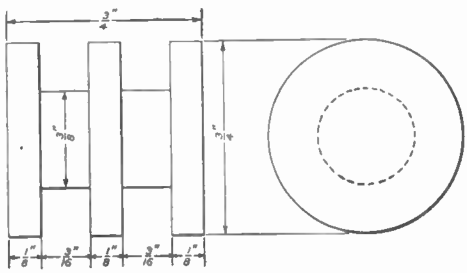


FIG. 2

13. About 50 to 75 turns of wire should be used on each winding of a radio-frequency transformer to amplify signals near the 200 meter wave-length range. A coil having 100 to 300 turns will give transformers that should operate on the range of wave-lengths of 300 to 600 meters, intermediate wave-lengths being best amplified by intermediate numbers of turns. No. 40 B. & S. gauge copper wire, enamel-covered, is very satisfactory for radio-frequency transformer coils. A double-silk covering is also very good, while considerable preference is given to wire covered with enamel and one layer of silk. Larger sizes of wires do not usually work so well in radio-frequency transformers.

14. Iron-core radio-frequency transformers may be considered all those in which the magnetic path is partly or entirely through iron. The magnetic path may consist of a few layers of thin pieces of iron or silicon steel placed within the coils, or a complete magnetic path may be provided through iron within the coils and surrounding them. The amount of iron used depends largely upon the requirements of the transformer.

The core should be built up of very thin sheets, called *laminations*, of special grades of iron, so as not to have too great losses in this part of the circuit. The general effect of an iron core is to broaden the wave-length range over which the coil will amplify, while reducing the tendency of the transformer to amplify signals at one particular frequency so as to cause oscillations. Iron-core radio-frequency transformers, especially those having complete iron cores, ordinarily have smaller stray fields than do those of other types. Radio-frequency transformers that are used in special sets will be described in connection with those sets.

An iron core for radio-frequency transformers should be built up of layers of rolled iron or steel, each lamination having a thickness of not more than .005 inch. Small sheets ½ inch wide by 3 inches long might be built up to a thickness of ½ inch to form a convenient-sized core. Although steel may be the actual material used, transformers with magnetic cores are commonly classed as iron-core transformers. About the same turn ratio may be tried on iron-core transformers as with the air-core transformers.

15. Impedance-Coil Coupling.—The connection between successive stages of radio-frequency amplification may also be effected by means of impedance coils. These may be either tuned or untuned. In the case of the tuned coils, a suitable tapped coil shunted by a condenser is satisfactory for this purpose. Variometers are especially recommended for this use, since their inductance is continuously variable throughout their entire range.

Untuned impedance coils, usually called *choke coils*, are used to a considerable extent for coupling purposes. Just as the iron core tends to broaden the frequency range of a transformer, a similar iron core will have the same effect on the action of a choke coil.

Impedance coils used for coupling one radio-frequency stage to another, may be of the air- or the iron-core type, and may, further, be of fixed or variable inductance.

16. Resistance Coupling.—The coupling between the stages of a radio-frequency amplifier is sometimes obtained by means of resistors. The drop of potential across the resistance is utilized to affect the grid circuit of the next amplifier or detector tube. The disadvantageous feature of resistance coupling is that a much higher plate potential is required than for either the transformer or impedance coil coupling.

RADIO-FREQUENCY AMPLIFIER SETS

SIMPLE AMPLIFIER CIRCUITS

17. Single-Stage With Transformer Coupling.—The circuit of Fig. 3 shows the connections from a loop, or coil, antenna through one stage of radio-frequency amplification to a detector circuit. The coil antenna *a* is tuned by the shunt condenser *b*, from which the radio frequency signal is transferred to the grid circuit of the amplifier tube *c*. The grid return circuit connects with the slider of the potentiometer *d*. The filament current is adjusted by the rheostat *e*. The amplified signal passes through the transformer *f*, and the grid condenser *g*, which is shunted by the grid leak *h*, to the grid of the detector tube *i*. The grid condenser and grid leak help the detector to perform its detector action; that is, to convert the radio-frequency currents to audio-frequency signals in the telephone receivers *j*. The filament current of the detector tube *i* is controlled by the rheostat *k*, which should be of a type with which fine adjustments can be secured. The telephone condenser *l*, in shunt with the telephone receivers and part of the *B* battery, should help the reception of signals.

18. The filament current supply for both tubes is secured by means of an *A* battery, Fig. 3, of a size dependent upon the type of the tubes. The plate voltage is secured by the usual

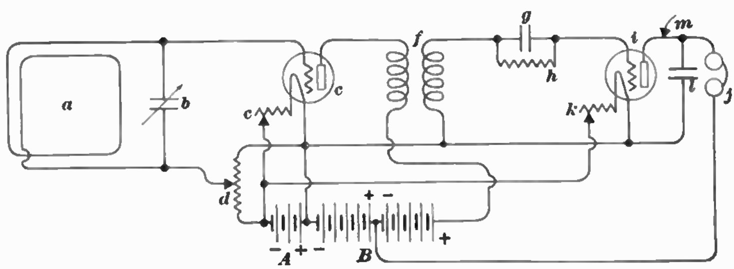


FIG. 3

B battery of the proper potential for radio-frequency operation. With a hard, or high-vacuum detector tube it is possible to use a fairly high plate potential, but the connection should be tried on lower plate voltages for the detector, and left there if improved operation results. No *C* battery is required, as the proper grid bias on the amplifier tube is secured by the adjustment of the potentiometer.

With the two tubes operating properly, there is one main tuning element, and some auxiliary aids to good tuning. The coil antenna *a* should be rotated so as to intercept signals from the desired station, after which it is tuned to that station by means of the shunt condenser *b*. For accurate tuning, especially to weak signals, the condenser should have a vernier adjustment. The desired signal will then be amplified by the amplifier tube *c* and further by the radio-frequency transformer *f*, if the signal is within its operating range.

19. The grid-return lead of the amplifier tube *c*, Fig. 3, may be connected to the negative *A*-battery terminal for maximum amplification. At radio frequencies there is a feed-back from the plate to the grid circuit which easily sets up a state of oscillation in the tube *c*, and its auxiliary circuit. This oscillating radio-frequency current blocks the reception of signals. Since this oscillation is at frequencies much above the audible range it may occur without the knowledge of the operator that such is happening.

To overcome the tendency of the set to oscillate, some transformers are made of wire possessing considerable resistance. The tendency to oscillate may be controlled to some extent by connecting the grid return of the amplifier tube to the potentiometer across the *A* battery. This will ordinarily not give quite so good operation of the tube, but is certainly more desirable than the oscillating condition of the set. The grid return connected to the potentiometer, as shown in Fig. 3, makes it possible to secure a bias that will just stop oscillations, and give maximum amplification. In practice, with one stage of radio-frequency amplification, the set will be found to work best with the slider connection near the negative terminal. An auxiliary tuning effect is also secured by regulating the filament current in both tubes, which is apt to be rather critical, especially on the detector tube. The telephone condenser *l* may not have much effect on the operation of the set, a feature that is somewhat dependent on the wiring of the set, and on the construction of the telephone receivers.

20. The effect of a variometer in the plate circuit of a detector tube *i*, Fig. 3, is to tune that circuit so as to cause a feed-back of radio-frequency current into the grid circuit through the tube capacity. Suppose a variometer is inserted in the plate circuit at the point *m* and the set is adjusted so that it is nearly oscillating. If additional regeneration is produced by a variometer at *m*, or by other means at any other part of the circuit, it will merely cause the set to oscillate. It may so happen, however, that the circuit conditions will permit of an appreciable amount of additional regeneration in the plate circuit of the detector tube before prohibitive oscillations start.

A positive bias on the amplifier tube will tend to prevent the establishment of oscillations. This would be accomplished by the adjustment of the potentiometer. The variometer in the detector-tube plate circuit could be employed to secure regeneration almost to the point of oscillation. Ordinarily the signal strengthened by the plate variometer will not be much greater than it was before applying the positive bias to the amplifier tube. The addition of the regenerative feature has, therefore, not given much increase in signal strength, while adding another tuning element. In practice, it is very common not to use a variometer in the plate circuit of the detector tube, but to depend upon the grid return potentiometer on the amplifier tube to control the tendency of the radio-frequency amplifier tube *c* to oscillate. That the tube is forced to remain in a state just below oscillation, however, does not mean that it does not operate satisfactorily. The clearest amplification free from distortion occurs when the tube and its circuits are stable electrically.

21. One stage of radio-frequency amplification will increase the operating range of any set. Added to a regenerative set, it will minimize the disturbances or interference produced by the set, and at the same time increase the range of the set considerably. Radio-frequency amplification with transformer coupling is not limited to one stage. Two or even more stages may be used, provided the proper precautions are taken to prevent the distortion of signals. With an outside aerial of the **L** or **T** types, the amplification of signals at radio frequency does all that is applicable to the loop aerial, without destroying the increased original signal intensity.

22. Single-Stage With Tuned Impedance Coupling. Tuned impedance, when properly designed, forms a very good radio-frequency coupling. The impedance coil may be a variometer, or a tapped coil. The tapped impedance coil often has a variable condenser in parallel as an adjunct to fine tuning.

One stage of radio-frequency amplification coupled to a detector circuit by means of a variometer is represented in Fig. 4. The antenna variometer *a* should have enough impedance to enable the antenna circuit to be tuned to the highest wave-length it will be expected to receive. Sometimes an antenna condenser is connected in series with the antenna lead with considerable improvement in the operation and tuning of the set. The variometer is connected directly into the grid circuit of the amplifier tube *b*. The variometer *c* is used for coupling the amplifier circuit to the detector circuit. Since the B_1 battery voltage is applied to the variometer *c*, it is necessary to insert a small condenser *d* in the grid lead to the succeeding

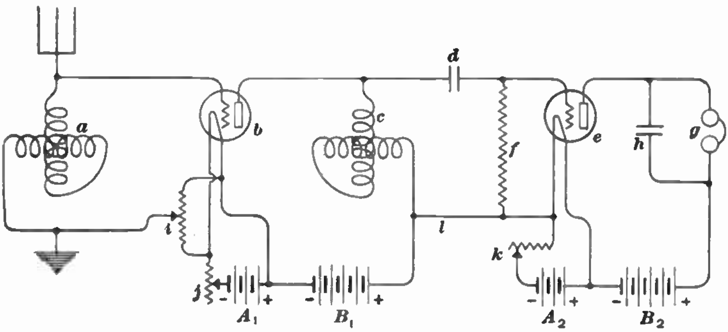


FIG. 4

tube *e*. If such a condenser were not put in the grid lead, the plate voltage would render the succeeding tube inoperative. A rather high-resistance grid leak *f* is essential if the tube across which it is connected is a detector, as in this case. A high-resistance grid leak helps stabilize the action of the tube following a tuned impedence coupling with grid condenser, even if that tube is another radio-frequency amplifier tube.

23. The telephone receivers *g*, Fig. 4, may be shunted by a small condenser *h*, if necessary. A variometer in the plate circuit of the detector tube *e* will sometimes give additional signal strength, but is not considered necessary for good results. Since the positive terminal of the battery B_1 is connected to the filament of the next tube *e*, it is necessary to have a separate set of *A* and *B* batteries for each tube. With small-energy tubes this is not quite so objectionable, and the plate potential on the detector tube need not be very high. A potentiometer *i* often aids considerably in controlling the tendency of the set to oscillate at radio frequency by applying a positive bias on the grid return of the amplifier tube *b*. This type of circuit is particularly subject to oscillation due to the interaction between the tuning coils, which are likely to have considerable effect upon each other. With individual *A* batteries, separate rheostats, as at *j* and *k*, are necessary. If the wire *l* is removed the two tubes may be operated by one *A* battery.

24. The advantages of a tuned variometer coupling have been applied by at least one manufacturer. The variometer is made with a double winding; that is, two sets or strands of wire wound side by side, but insulated from each other. One winding is connected between the positive *B*-battery terminal and the plate of the amplifier tube. The other winding acts as a secondary and is connected with one terminal to the grid of the next tube, and the other terminal, as the grid return, to the negative or positive filament lead of that same tube. The negative or positive filament connection depends on the type of tube used. As this auxiliary winding is insulated from the winding in the plate circuit, a grid insulating condenser and leak resistance is not necessary except in the input to the detector tube. This also means that separate *A* and *B* batteries are not necessary, a fact of considerable importance. Since this type of coupling transformer is tuned, it helps the set in obtaining good selectivity between stations.

This set should be tuned by the main tuner with the special transformer set as far as possible from its tuned position, then the special transformer should be adjusted for the best operating condition. If the setting is kept slightly below resonance, conditions are such that the amplifier is stable, and does not tend to set up oscillations.

25. Two Stages With Choke-Coil Coupling.—The air-core transformer in general is quite efficient, but is apt to have rather sharp tuning. The iron-core transformer usually has

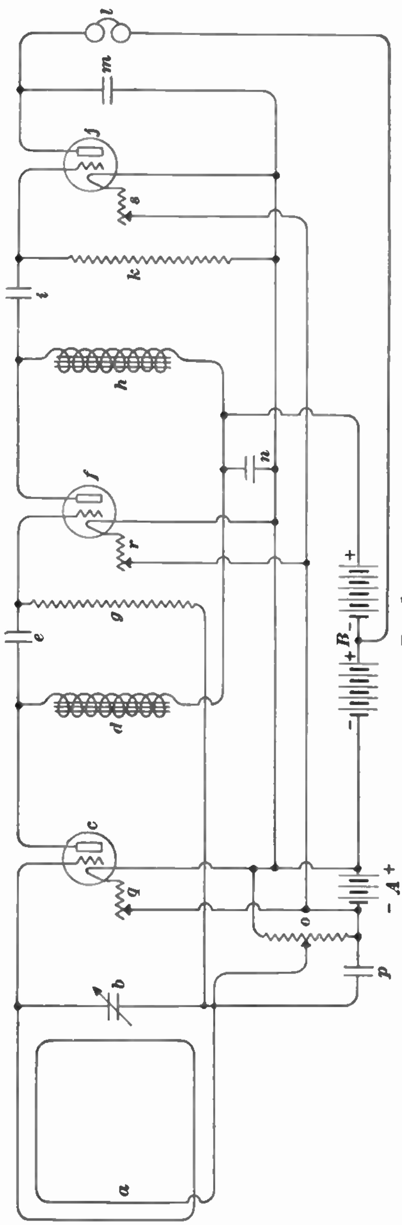


Fig. 5

characteristics making it suitable for operation over a band of wave-lengths, but with some reduction in output over that given by an air-core transformer. A choke-coil coupling combines the advantages of each. The result is not entirely free from the disadvantages of the previously mentioned transformers, but does form a simple type of coupling. The choke coil may also be tapped, so as to make it more or less selective to signals over a certain band of wave-lengths on each tap. This is an aid to selective tuning since the choke coils tend to help tune the set as a whole to the desired signal.

The radio-frequency amplifier shown in Fig. 5 has iron-core choke coils as the main interstage coupling devices. The input circuit consists of a coil, or loop, antenna *a*, although it would be possible to substitute a tuning coil coupled to an **L**- or **T**-type antenna system. The input circuit is tuned by the variable condenser *b*, which should have a vernier adjustment for accurate tuning. The signal is strengthened by the amplifier tube *c* and sent on to the coupling coil *d*. The choke coil employed as a coupling device acts to all intents and purposes like a one-to-one ratio transformer or tends to approach it in operation. It is well to note that some double-winding transformers have only a one-to-one turn ratio, or at least that effect, so that the one-to-one choke-coil ratio, if it is obtained, is not a serious consideration. The amplified signal causes voltage variations across the choke coil which are impressed through the condenser *e* on the second amplifier tube *f*. A grid leak *g* is necessary, even on an amplifier tube, to prevent the grid from collecting enough electrons to kill the action of the tube. A grid leak, of 1 megohm or higher, will permit any electrons which may settle on the grid to leak off, before enough combine to set up a negative charge on the grid. Although the grid-condenser and grid-leak combination gives some rectification of the signal, this rectified part is lost, as the amplifier will not operate with such signals. However, there is enough radio-frequency energy available in the plate circuit for further amplification. The signal then goes to the second choke coil *h*, by means of which it is transferred to the detector circuit including the grid condenser *i* and the detector tube *j*. The grid leak *k* helps the grid condenser *i* in its function of causing the three-element tube *j* to act as a detector of the high-frequency signals. The signal current, now at audio frequency, can actuate the telephone receivers *l*.

26. The telephone shunt condenser *m*, Fig. 5, acts as a by-pass for the radio-frequency currents around the telephone receivers, and also helps smooth out the audio-frequency currents. This condenser might be connected across the telephone receivers only. The shunt condenser *n* provides a good path for the radio-frequency currents around the *B* battery. These two by-pass condensers should each have a capacity in the neighborhood of .0005 to .002 microfarad, or even larger, but the values should not be critical; that is, the fixed condensers should be adaptable to a considerable range of operating conditions.

The potentiometer *o* permits of obtaining various grid-bias values on the radio-frequency tubes for controlling the strong tendency of such tubes and circuits to oscillate. Since the fineness or accuracy of this adjustment depends upon the size of the voltage steps between turns, it is important that there be a large number of turns on the potentiometer. A potentiometer with a resistance of 400 ohms has more turns of wire than one of lower resistance, so is capable of giving more accurate adjustments or settings of voltage over its limited range of values. It is also well to put a switch in series with the potentiometer, which switch should be opened when the set is not in use, to prevent the loss of current from the *A* battery. A small fixed condenser *p* of .002-microfarad capacity or larger will serve as a by-pass for radio-frequency currents around such part of the potentiometer resistance as may be included in the circuit.

The rheostats *q*, *r*, and *s* give individual filament control of the tubes *c*, *f*, and *j*, respectively. The two radio-frequency amplifier tubes *c* and *f* could be controlled by a common rheostat, but some advantage can often be gained with a separate rheostat for the filament control of each radio-frequency amplifier tube. The rheostat on the detector tube should be of the vernier type so that it will be capable of giving fine adjustments of filament current. If the detector tube is of the soft, or gassy, type the plate voltage on that tube should be low, about 16 to 20 volts. An extra potentiometer across the *A* battery with the slider connected to the negative *B*-battery terminal will often help give accurate plate-voltage adjustments with such tubes.

With tapped choke coils, better results are obtained when the coil is properly tuned. When several similar coils are used it is advantageous to use a mechanical control for setting all the coils for a given wave-length simultaneously.

27. Resistance-Coupled Amplifier.—A resistance-coupled amplifier utilizes fixed resistance units as the coupling devices between the amplifier tubes. In practice, resistance-coupled radio-frequency amplifiers do not work well on the shorter

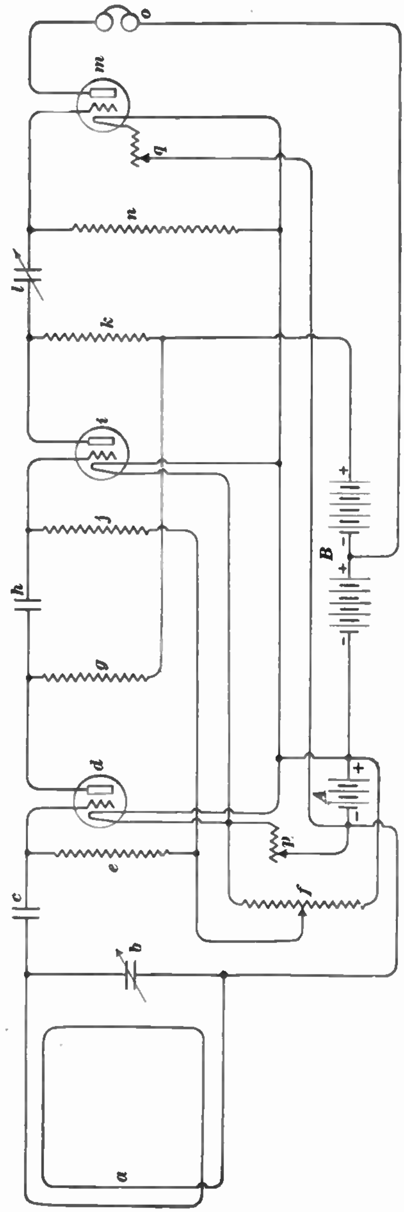


FIG. 6

wave-lengths, and their use is practically limited to the amplification of signals on wave-lengths of about 2,000 meters or more. On such wave-lengths the operation of resistance-coupled amplifiers is very satisfactory, but has been largely replaced by other types of coupling not requiring such high plate voltages.

In Fig. 6 is shown the arrangement of apparatus in a radio-frequency resistance-coupled amplifier. The rather large loop, or coil, antenna *a* is tuned in the usual fashion by the shunt variable condenser *b*. The desired signal then passes through a fixed condenser *c*, of .00025-microfarad capacity, to the grid of the first amplifier tube *d*. The condenser *c* insulates the grid, so it is necessary to use a fixed grid-leak resistance *e* of about 2 megohms to control the grid and its bias. The grid leak connects with the slider of a potentiometer *f*, which control aids in securing the proper bias on the grid of the tube *d*. However, this bias is not very effective unless this leak resistance is relatively low.

28. The plate voltage is applied through the fixed resistance *g*, Fig. 6. This unit may have a resistance ranging from 50,000 to 100,000 ohms, and should be able to carry the plate current. Changes of plate current caused by the incoming signal, form voltage changes across the resistance *g* that act through the condenser *h* and are impressed on the grid of the tube *i*. The condenser *h* and a grid leak *j* possess the same numerical values as had the condenser *c* and the grid leak *e*. In fact, other stages of amplification could be added by duplicating the apparatus shown in the intermediate stage.

The fixed resistance *k* is identical with the resistance *g*, and it performs the same function. The signal is now detected by the grid condenser *l* acting on the grid of the tube *m*. The condenser *l* should have a capacity of .00025 to .0005 microfarad and some benefit may result if it is variable. A grid leak *n* of a resistance of 2 to 5 megohms is necessary to complete the detector action. The signal can now be sent through the telephone receivers *o*, or further amplified for greater intensity. One rheostat *p* will control the filament current of all the radio-frequency amplifier tubes. Another rheostat at *q* gives accurate filament control for the detector tube. The *A* and *B* batteries will depend to a considerable extent on the type of tubes used. In general, an especially high plate voltage is necessary on resistance-coupled amplifier tubes, and 120 volts will be a suitable value with this circuit. Such high voltages are not desirable on the detector tube, and a separate low-voltage tap is necessary.

29. Other values of intermediate resistances, and especially higher values, may be tried in radio-frequency work. If the resistance in the plate circuit is increased considerably, it will be necessary to raise the applied plate voltage. Even smaller values of coupling capacities than those mentioned should suffice in radio-frequency amplification. It is desirable to use mica or glass as the dielectric of the fixed condensers, as paper is apt to cause noises. It will be necessary to use a heterodyne or separate oscillator to make it possible to receive undamped-wave telegraph signals with this set. The oscillator may be coupled with the coil antenna, or with the input to the detector tube.

NEUTRODYNE AMPLIFIER SET

30. Principle of Operation.—In the ordinary radio-frequency amplifier there is apt to be considerable coupling between the successive stages, which coupling tends to cause oscillating currents to be established within the set. For example, there may be mutual induction between two or more of the air-core coupling transformers, due to the magnetic flux from any one of the transformers acting on the windings of the other transformers. This effect may be eliminated by arranging the coils so that the flux from one transformer cannot induce voltages in any other coil. By placing the axes, or center lines, of all the coils at right angles with each other the inductive effect will be considerably reduced. For example, in an amplifier with three such sets of coils, one could be stood on end, one laid flat with one end toward the observer, and the other laid flat but with one side toward the observer. When properly placed each coil would form a right angle with each of the other coils. Another method of eliminating coil coupling is to locate all the similar coils, say three, parallel to each other but so that they form an angle just over 55 degrees with the horizontal.

31. There is an appreciable electrostatic capacity between the grid and plate of a commercial type of tube. At radio frequencies this capacity acts as a coupling condenser and tends to establish radio-frequency oscillating currents in the set. The significant achievement of the neutrodyne set is the neutralization of this tube capacity so as to secure operation free from the tendency to oscillate.

The neutralization of the tube capacity is secured by feeding energy from another source back into the grid circuit to buck and neutralize that fed back by the grid to plate capacity. In order to get a current that will buck or neutralize the undesired

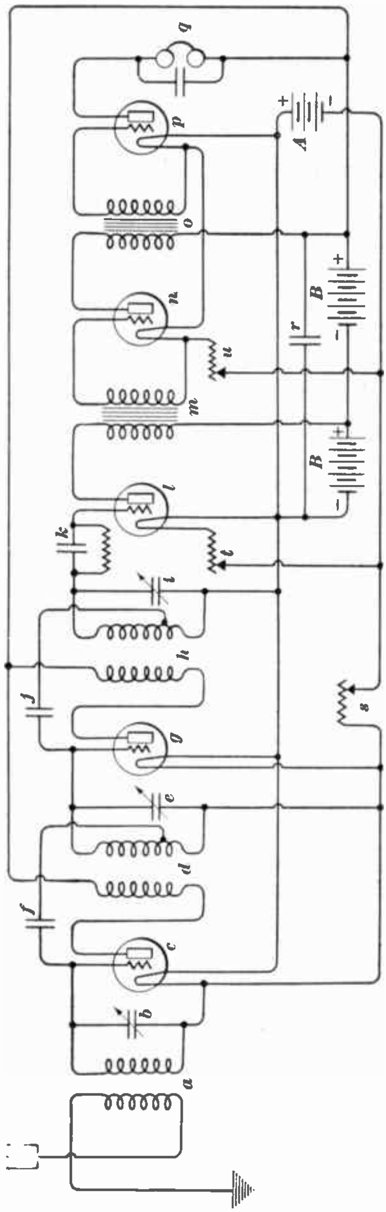


Fig. 7

coupling it is necessary to take it from a coil coupled to the plate circuit coil. In practice the neutralizing energy is taken from the usual secondary coil which is connected to the grid circuit of the succeeding tube. A lead from this secondary coil is then connected to a very small adjustable condenser and the connection is then completed to the grid circuit of the offending tube. The neutralizing condenser may be of a larger size, and less critical in adjustment, if the secondary connection is made at a point part way along the coil, which is a departure that is made in many of the commercial sets. The neutralizing condenser is normally adjusted once for any certain type of tube, and should not need to be readjusted in receiving signals over a considerable wave-length range with tubes of that type.

32. Circuit Connections.—The circuit connections of a neutrodyne set are given in Fig. 7. The antenna and ground connections of the transformer *a* are apparently reversed, but this is done to keep the coil consistent with the others, which must be mounted so as to give the proper phase relations or bucking effects. This set may give good results on a coil antenna, but a moderately long L- or T-type antenna is recommended. The primary and secondary windings of the transformers are quite close together, so the primary coil is tuned to a considerable extent even though there is a tuning condenser across the secondary winding only. The tuning of all three air-core transformers makes the set quite selective.

The input circuit is tuned by the shunt condenser *b*, and the secondary circuit is connected directly across the grid and the filament of the first tube *c*. The plate circuit of the tube *c* supplies its energy to the transformer *d*, which has its secondary tuned by the condenser *e*. The tap for the neutralizing condenser *f* is connected at such a point along the secondary of the transformer *d*, usually about one-fourth the distance from the filament end to the grid end, as to give the proper relation of the feed-back current and a fairly large value of current to the condenser *f*. The capacity of the condenser *f* is normally very small, but if the connection to the secondary coil is made near the bottom end, a larger condenser is required at *f* with a consequent ease of adjustment.

33. The amplifier tube *g*, Fig. 7, next receives the energy and feeds it to the transformer *h*, which is identical with both the transformers *a* and *d*. The condenser *i* tunes the secondary circuit of the transformer *h*. The small adjustable condenser *j* feeds enough of the proper kind of energy, opposite in phase, into the grid circuit of the tube *g* to neutralize the direct feed-back of the tube capacity between the grid and plate elements. The grid condenser and grid leak, shown at *k*, perform their usual functions to help the detector tube *l* make the received signal audible. The audio-frequency energy is transferred from the plate circuit of the detector tube *l* by means of the audio-frequency transformer *m* to the grid circuit of the amplifier tube *n*. The signal is further amplified by the transformer *o* and the tube *p* and finally translated to sound by means of the telephone receiver *q*. The condenser *r* is one of fairly large size and acts as a by-pass for radio-frequency currents around the *B* battery. Although individual rheostats may help some, one rheostat at *s* will satisfactorily control the filament operating conditions of the radio-frequency amplifier tubes *c* and *g*, a separate rheostat *t* for the detector-tube filament control is very common, and practically a necessity. The audio-frequency tubes *n* and *p* are also controlled by one rheostat *u*.

The *A* battery should be of a size and type suitable for operating the particular tubes that are selected. The *B*-battery voltage should be fairly high, say 90 volts, but not so high as to cause distortion. The grid return of each of the amplifier tubes *c*, *g*, *n*, and *p* connects with the negative filament lead. Since the set, when properly adjusted, cannot oscillate, it is not necessary to use a potentiometer to secure losses which will prevent oscillations. A *C* or grid-bias battery may be used to clear up the signal and reduce the plate current if a high plate voltage is applied. The grid return on the detector tube should go to the positive filament terminal, if the detector tube is a so-called hard, or high-vacuum, tube.

34. The adjustment of a neutrodyne set may be made with the aid of a wavemeter or the signals from strong local stations. The buzzer-excited wavemeter should be placed several feet from the set, and connected by a single wire from one end of the wavemeter coil to the antenna connection on the set. The ground terminal on the set should be connected to ground. The set should be carefully tuned to the signal by adjusting the three tuning condensers *b*, *e*, and *i*, Fig. 7, for maximum signal strength. The first tube should be removed and a small piece of paper placed on one of the filament contact springs in the socket so as to keep open the filament circuit. The tube should then be replaced in its socket and the neutralizing condenser *f* adjusted until no signal is heard in the telephone receivers. The small piece of paper is then removed and the procedure repeated for the next amplifier tube. Occasionally it happens that the circuit lead wires have

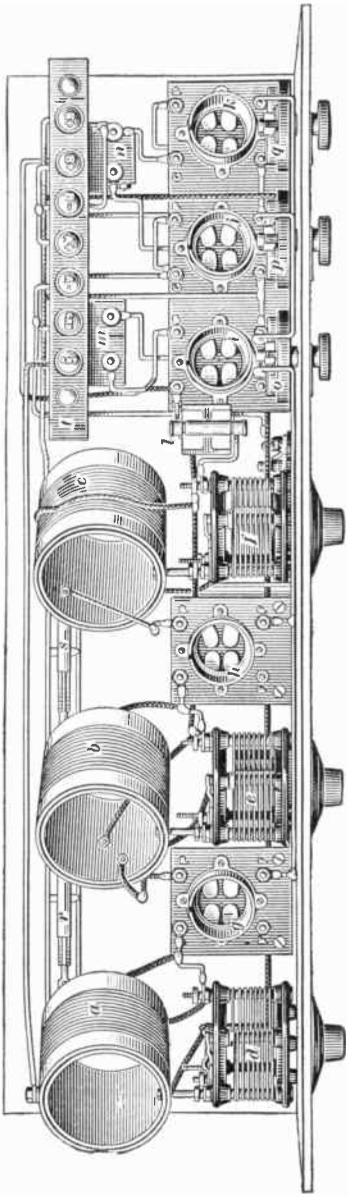


FIG. 8

more than enough capacity to neutralize the grid to plate capacity. In such a case additional grid to plate capacity must be added, but such sets are apt to operate rather poorly. When the neutrodyne set is properly neutralized, it should be entirely free from oscillations set up within the set, even when the tubes are forced, that is, operated with the filament conditions above normal.

35. Construction of Neutrodyne Set.—The manner in which the parts of a neutrodyne set are mounted on a panel is indicated in the plan view, Fig. 8. The three radio-frequency transformers *a, b,* and *c* (*a, d, h,* Fig. 7) are fastened to their respective condensers *d, e,* and *f* (*b, e,* and *i,* Fig. 7). The condensers are, in turn, firmly attached to the panel with the shafts extending on the opposite side of the panel. On each condenser shaft is placed a dial with a knob for turning the movable plates of the condensers. The sockets *g* and *h* are for the radio-frequency amplifier tubes. The detector tube is placed into the socket *i*, and the two audio-frequency amplifier tubes are inserted into the sockets *j* and *k*. The grid condenser and grid leak are mounted as indicated at *l*. The two audio-frequency transformers *m* and *n* should be so arranged that there will be no induction between them. The rheostat *o* controls the filament current of the radio-frequency amplifier tubes. The rheostat *p* is for the detector tube, and the rheostat *q* for the two audio-frequency amplifier tubes. The neutralizing condensers *r* and *s* are placed near their respective transformers and also near the tubes whose grid to plate capacities they are to neutralize. All the binding posts for completing connections to outside devices, such as the antenna, the ground, and the batteries, are mounted on a special panel *t*; the top of each binding post has a designation so as to enable the operator to make the proper connections.

36. The primary winding of each of the radio-frequency transformers *a*, *b*, and *c*, Fig. 8, consists of approximately 15 turns of No. 26 B. & S. gauge double-cotton covered wire wound on a 3-inch paper or composition tube. The secondary winding is wound with similar wire on a 3½-inch tube with approximately 60 turns of wire. The 3-inch tube which carries the primary winding is then inserted into the tube carrying the secondary winding.

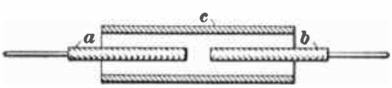


Fig. 9

The mounting position of each of the radio-frequency transformers should be noted. Each of the transformers is tilted so as to eliminate or at least minimize the induction effects between adjacent coils.

A cross-section of a neutralizing condenser (*r* and *s*, Fig. 8) is shown in Fig. 9. The two insulated conductors *a* and *b* are extensions of the connections to the grid and the secondary of the radio-frequency transformer. Over these conductors, separated as shown, is placed a copper tube *c*. As the tube is moved over the conductors the capacity is correspondingly varied. There are many other types of neutralizing condensers, the foregoing being simply one method of obtaining the desired result.

SUPERDYNE AMPLIFIER SETS

37. Reverse Feed-Back.—In every radio-frequency amplifier set there is a constant tendency for the set to oscillate, due to the feed-back action between the elements of the radio-frequency amplifier tubes. In the neutrodyne system the tendency to oscillate is considerably reduced by feeding energy from another circuit by means of neutralizing condensers. This neutralizing energy may also be fed inductively, and is so done in the **superdyne system** of amplification. The basis of this system is a coil in series with the plate circuit and coupled to the grid inductance in such a manner that some energy is transferred by induction into the grid circuit of the amplifier tube so as to oppose the feed-back effect caused by the capacity of the tube.

38. Circuits and Construction of Superdyne Set.—One type of superdyne set is shown in Figs. 10 and 11. In Fig. 10 are shown the circuit connections, and in Fig. 11 one possible arrangement of parts. Reference should be made to Fig. 10 for the continuity of circuits, and to Fig. 11 for locating the parts under consideration. Similar reference letters are used to designate corresponding parts in both figures.

The coil *a*, connected between the antenna *A* and the ground terminal *G*, consists of 4 turns of wire wound on top of the coil *b*. The coil *b* forms the secondary and is wound on a 4-inch coil form. A tap at 20 turns enables tuning to the shorter amateur wave-lengths, while the full 42 turns on the coil give a range to somewhat over 600 meters with a variable condenser *c* having a maximum capacity of .0005 microfarad. The switch *d* permits of using either 20 or 42 turns of the coil *b*.

The amplifier tube *e* amplifies the received signal at radio frequency and sends it on through the set. The coupling to the next tube, which is the detector, consists of a tapped coil *f* shunted by the .0005 variable condenser *g*. The coil *f* has 46 turns and is tapped at the 25th turn. Connections are made to switch points from the 25th turn and the last turn so that

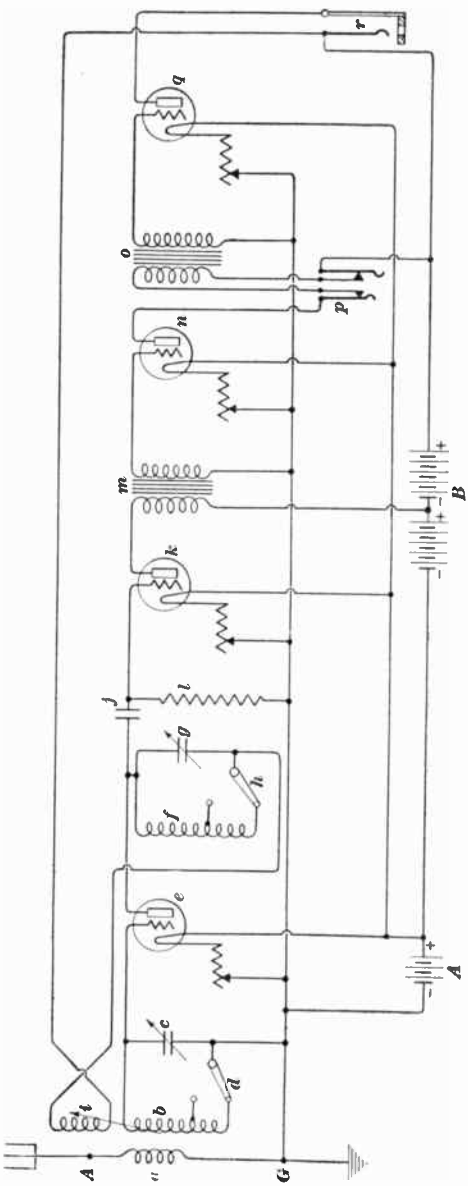


FIG. 10

by moving the switch arm *h* to either one of the two contacts the desired number of turns may be used. The tap on the 25th turn of the coil *f* is for the shorter wave-length range. The longer wave-length range may be secured by using all 46 turns of the coil *f* in parallel with the condenser *g*. In this manner both the input and coupling circuits are readily tuned to the desired station, which feature permits of good selectivity. The coil *f*, like the coil *b*, is wound on 4-inch tubing, and preferably of No. 22 insulated copper wire.

39. The plate circuit of the amplifier tube *e*, Figs. 10 and 11, also includes a tickler coil *i* of 36 turns of wire wound on a rotor to be used in connection with the coil *b*. The leads to this coil are shown reversed in Fig. 10,

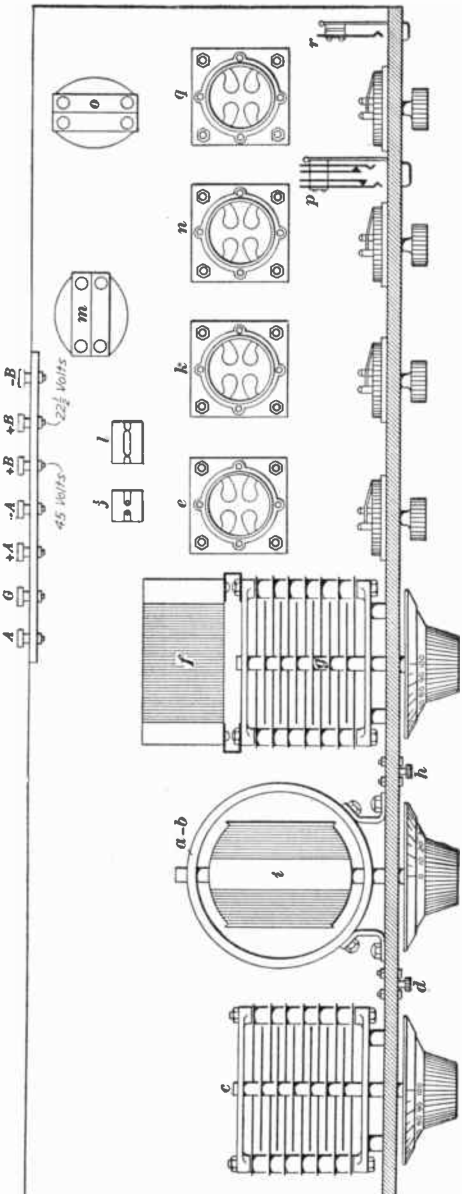


FIG. 11

which is done to emphasize the fact that this coil is connected so as to counteract the feed-back caused by the grid to plate capacity in the amplifier tube *e*. The effect of the tickler in this case is just opposite to that desired in a regenerative receiver, since in the latter the tickler coil is connected so as to help produce a feed-back of energy, which does not oppose but r a t h e r aids the energy that is fed by the tube capacity. In operation the tickler coil of the superdyne set is adjusted so as to prevent oscillations in the amplifier circuit and under these conditions of neutralization operation of the set should be at its best.

The amplified signal then goes through the small fixed coupling condenser *j* of .00025-microfarad capacity. The signal is reduced to audio frequency by the usual detector tube *k*. The grid leak *l*, with a resistance in the neighborhood of two megohms, performs its usual function of permitting charges which accumulate on the grid to leave it at a moderate rate.

40. The plate current passes from the 22½- or 45-volt tap on the *B* battery, Fig. 10, through the primary winding of the audio-frequency transformer *m*. The voltage induced in the secondary winding is impressed on the grid circuit of the amplifier tube *n*. In series with the plate of the tube *n* is the primary winding of the audio-frequency transformer *o* and the jack *p*. By placing a plug to which a pair of telephone receivers is attached into the jack *p*, signals may be listened to on the first stage of audio-frequency amplification. As soon as a plug is placed into the jack the outer springs of the jack are spread apart and the primary of the transformer *o* is cut out of the circuit. If the second stage of audio-frequency amplification is to be used, the jack *p* remains in its normal position with no plug in it so that the plate energy passes through the primary of the transformer *o*. The voltage induced in the secondary winding of the transformer affects the amplifier tube *q*. The output of this tube is through the jack *r*, into which a plug connecting with telephone receivers or a loud speaker may be inserted.

Individual rheostats are provided for all the tubes, so as to obtain a better control of the filament current. One rheostat may be used for the two amplifier tubes *n* and *q*.

SUPER-HETERODYNE RECEIVER

41. The *super-heterodyne* radio receiver represents what is generally conceded to be one of the most sensitive if not the most sensitive radio-receiving set. It also possesses a very high degree of selectivity in tuning to the desired station with a minimum of interference from signals on other wavelengths. Since the super-heterodyne normally operates on a loop, or coil, antenna, it does not, as a rule, affect other receiving sets.

The sensitive limit of any set depends upon a factor often known as the *static level*. As the sensitivity of a set to weak signals is increased, the set responds to these feeble signals but it also picks up static and other extraneous noises. When extreme sensitiveness is secured the static is apt to be so strong relatively as to render the signals unintelligible. The dividing line, although not definite nor constant, at which the static renders the signal unintelligible, is known as the static level. The super-heterodyne when operating properly, is able to get down to this so-called static level. Greater sensitiveness than this is useless as it cannot be used even if it could be obtained readily.

42. Radio-frequency amplification has met with some success on short wave-length signals, although the losses are often very large. Better success is realized in the amplification of the longer wave-length signals since the frequency is less and the losses and other detrimental factors are not so great. The super-heterodyne, which is especially useful on short wave-length signals, changes the incoming radio-frequency signal to a lower radio frequency at which frequency the signal is amplified, subsequently detected, and later amplified at audio frequency in the customary manner. This is the basic principle of the super-heterodyne set.

The number of tuning controls for the super-heterodyne is not large, and, as the set has been developed, is practically accomplished by two main controls. Some other adjustments are usually necessary in getting a new set to operate properly, but once made they should need little attention. Since the intermediate transformers always amplify signals of one fixed frequency, they may be specially designed to operate very efficiently with signals of that particular frequency. Although a large number of tubes are used, each tube actually contributes to the reception of the signals, unless the set is so constructed that some of the tubes perform a multiplicity of duties.

43. A wiring diagram of a super-heterodyne set is given in Fig. 12. The loop, or coil, antenna *a* is tuned to the desired signal by the variable condenser *b*. The tube *c* is known as the first detector tube, and receives the incoming energy after

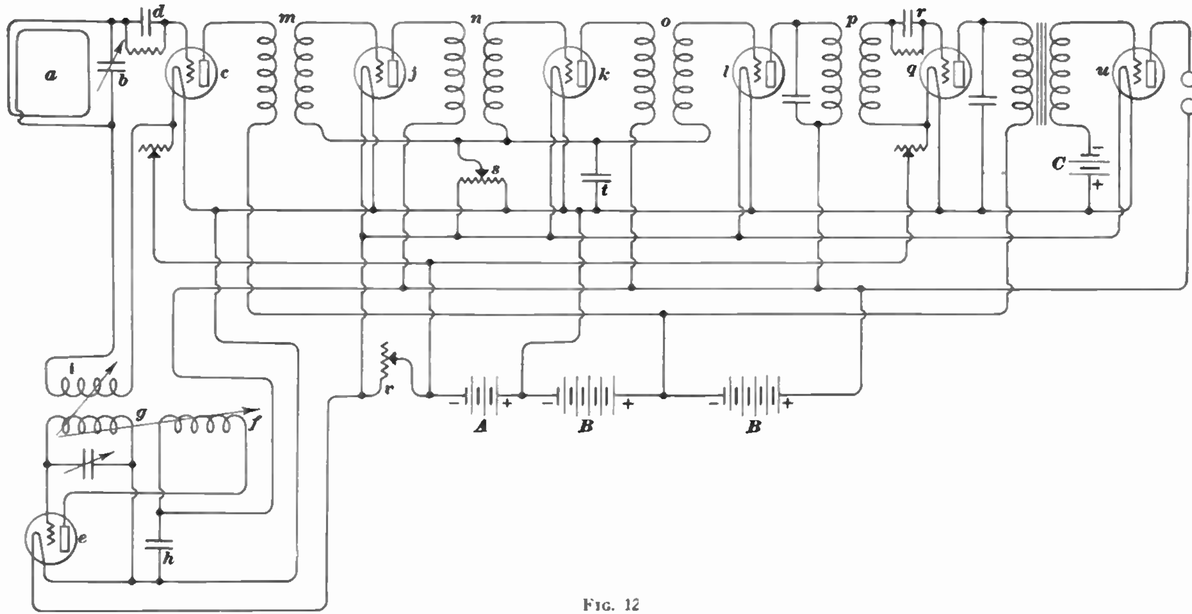


FIG. 12

it passes through the grid condenser *d*. A separate oscillator tube *e* generates a current at a frequency very close to that of the received signal. The plate circuit of tube *e* includes the coil *f*, which is coupled with the grid coil *g*. The grid coil is tuned by a shunt condenser, which condenser tunes the oscillator circuit to any desired frequency. A fairly large fixed condenser *h* acts as a by-pass around the *B* battery for the local oscillating current. This condenser helps to keep the oscillating current out of the other circuits.

Some of the oscillating current is fed from the coil *g* to the coil *i* in the grid circuit of the tube *c*. When the current from the tube *e* is nearly the same in frequency as that picked up by the coil antenna, a relatively low-frequency beat current will be established in the input circuit. For instance, if the incoming signal has a frequency of 1.000.000 cycles per second, corresponding with a wave-length of 300 meters, and the oscillator is tuned to and supplies a frequency of 1,050,000 cycles per second, these two currents tend to modulate, or beat with, each other. This beat-current envelope will have a frequency equal to the difference between the two combined higher-frequency currents, and the resulting signal strength may be somewhat increased over that of the components.

In the case under consideration the difference in frequency between the 1,000.000-cycle incoming signal and the 1.050,000-cycle local oscillator current is 50,000 cycles. A lower frequency, namely 950,000 cycles per second, supplied by the oscillator tube *e* and its circuit, would serve equally well; in fact, signals may be received under either condition in an actual set. The two high-frequency currents lose their identity when the new high-frequency current with the lower-frequency beat-current envelope is formed, and this resultant current is rectified, or demodulated, by the first detector tube *c* with its auxiliary circuit.

44. The three intermediate amplifier tubes *j*, *k*, and *l*, Fig. 12, together with the special coupling transformers *m*, *n*, and *o*, amplify the signals passed by the first detector tube. These tubes with their auxiliary circuits may be considered as a whole as an intermediate-frequency amplifier. If the intermediate-frequency amplifier is to be tuned permanently to some particular frequency, it may be very efficiently designed and will also help filter out many undesired signals. A condenser across the primary or secondary winding of the coupling transformer *p* aids considerably in obtaining exact tuning. The intermediate frequency should be well above audibility and at some radio-frequency that will amplify well. A frequency of 50,000 cycles serves these requirements very well and is very common in practice.

The incoming signal which, by way of example, was changed to a frequency of 50,000 cycles would be amplified by the tubes and circuits of the intermediate-frequency amplifier, and supplied to the second detector tube *q*. This tube by the aid of the grid condenser *r* and its grid leak changes the signal to an audio frequency.

The intermediate-amplifier tubes have their grid bias controlled by the potentiometer *s*. This potentiometer is adjusted with the slider in such position as to keep the tubes from oscillating. A by-pass condenser *t* provides a path for radio-frequency currents around the resistance of the potentiometer. The first detector tube *c* has an individual filament control rheostat.

45. From the second detector tube *q*, Fig. 12, the audio-frequency currents pass through a transformer to the audio-frequency amplifier tube *u*, which amplifies the signal at audio-frequency and sends it through the telephone receivers. If desirable one more stage of audio-frequency amplification could be utilized, although the one stage of audio will generally give a loud-speaker volume even on relatively weak received signals. A *C* battery, as shown connected to the grid of tube *u*, will give a negative bias that will help give better signals, with a saving in *B*-battery current. A separate rheostat controls the filament current of the second detector tube *q*, although this rheostat and the one for the tube *c* could be eliminated with little ill effect. In that case the filaments of both detector tubes would be connected with the large current-capacity rheostat at *v* which normally controls the filament current of all the amplifier tubes and of the oscillator tube.

As has been mentioned, the loop, or coil, antenna is tuned to the desired signal by the shunt condenser *b*. When the oscillator is tuned to a frequency 50,000 cycles away from that of the incoming signal, a 50,000-cycle beat note is produced that is amplified by the intermediate frequency amplifier. Frequencies very much to either side of this value will not be amplified appreciably if the amplifying transformers are properly designed. Two signals differing but slightly in their radio frequencies, will produce different beat frequencies. Only the beat frequency that corresponds with the resonance frequency of the circuit will be amplified properly.

46. It is good practice to use tubes of one type throughout the set. Unless the set is very carefully designed, the smaller-sized tubes are not apt to give as much output as may be secured by those using a greater amount of filament energy. The last audio-frequency amplifier tube is the one most apt to be overloaded to an extent great enough to cause distortion.

Although some commercial sets have been developed to a high degree, very good results may be secured by the use of special or even standard parts. Special intermediate-frequency amplifier transformers are desirable, but not essential, as any designed for a frequency close to 50,000 cycles will answer. If convenient, those wound with 500 to 600 turns on the primary, and with 600 to 2,000 turns on the secondary may be tried. No. 39 or 40 B. & S. gauge enamel and single-silk covered wire may be used, together with some iron as a core to broaden the wave-length range somewhat.

The oscillator coils may be purchased as a unit, or made from a variocoupler or a set of small honeycomb coils. The tuning condenser *b*, Fig. 12, and that across the coil *g* should be of a reliable make and certainly with a reliable vernier adjustment. If trouble is encountered in getting the set to operate quietly, it is sometimes effective to connect high resistances across the transformer windings, preferably the secondary, or to use by-pass condensers in various parts of the circuit.

SECOND-HARMONIC SUPER-HETERODYNE

47. The second-harmonic super-heterodyne set was developed for eliminating the necessity of a separate oscillator tube, which elimination is the distinctive feature of this set. The portion of the circuit dealing with this part of the set is given in Fig. 13. The coil antenna *a* is tuned in the usual manner by the condenser *b*. The signal then passes through the condenser *c* to the grid of the tube *d*, which amplifies the signal at

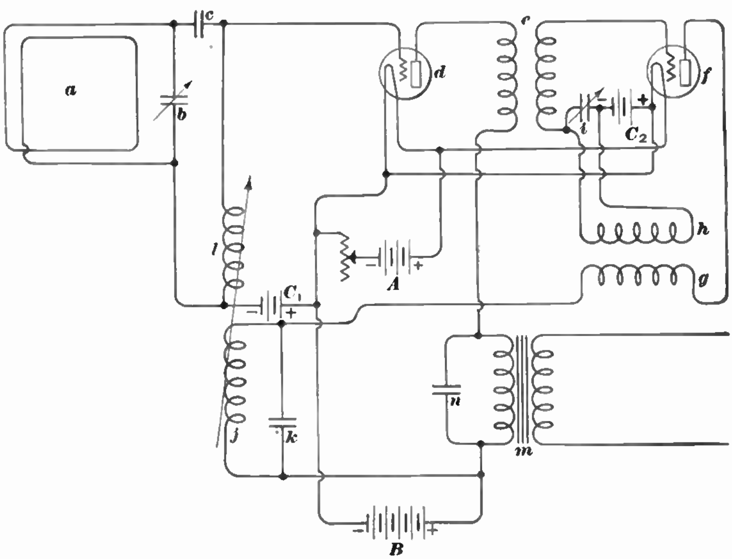


FIG. 13

radio frequency, just as received. The signal then passes, at radio frequency, through the transformer *e*.

The tube *f* is made to operate as an oscillator by the plate-circuit coil *g* coupled to the grid-circuit coil *h*, which coil is tuned by the variable condenser *i*. If the circuit formed by the coil *h* and the condenser *i* were tuned to a frequency almost the same as that of the incoming signal to produce the beat frequency, it would seriously affect the operation and tuning of the set. If this circuit is tuned to some considerably different frequency it will not have an injurious effect. An oscillating tube and its circuit produces harmonics or currents of other frequencies, which frequencies are multiples of the main fundamental frequency. If the circuit is tuned to a frequency of 475,000 cycles per second, there will also be a fairly strong current component with a frequency of 950,000 cycles per second. This second harmonic will produce a 50,000-cycle beat frequency with a signal of 1,000,000 cycles, and gives rise to the name applied to this type of receiver.

48. The coil *g*, Fig. 13, transfers the oscillating current to the grid circuit of the tube *f*, where its second harmonic combines with the incoming signal as in the super-heterodyne set. The beat or intermediate-frequency current passes through the coil *g*, since the coil *h* is not tuned to this beat frequency, and into the coil *j*, which is tuned by the shunt condenser *k*. The coil *j* is coupled with the coil *l*, which coil is in turn tuned closely by the condensers *b* and *c* in series. From the coil *l* the signal is impressed on the grid of the tube *d*, where it is further amplified at the intermediate frequency. Currents at the intermediate frequency pass through the primary of the transformer *e* to the primary of the transformer *m*, whose primary or input coil is tuned by the shunt condenser *n*. The signal now passes from the secondary winding of this transformer directly to the grid of the next intermediate amplifier tube.

The remainder of the set is similar in circuit arrangement and operation to the regular type of super-heterodyne. The filament current to both tubes *d* and *f* is controlled by one rheostat. The *A*, *B*, and *C* batteries could be common to all the tubes in the set.

COUPLING RADIO-FREQUENCY AMPLIFIER TO STANDARD RECEIVING SETS

INTRODUCTION

49. The radio-frequency sets described so far have considered the essentials of the radio-frequency amplifying systems and have also carried the received signal through the detector stage. This is usually the arrangement where head phones are used to receive the signals. Most commercial sets employ two stages of audio-frequency amplification following the detector tube to amplify or strengthen the signal to an extent great enough to enable it to operate a loud speaker. Some information will follow as to a few methods of applying or adding radio-frequency amplification to some typical styles of commercial radio-frequency sets. In general, the radio-frequency amplifier shown applied to any particular set, may be used in connection with most other commercial receiving sets, and the receiving sets illustrated are not limited to operation with only the radio-frequency amplifiers shown connected to them.

VARIOMETER TUNED TRANSFORMER COUPLING

50. The adaptation of one type of commercial radio-receiving set to operation from one stage of radio-frequency amplification is illustrated in Fig. 14. The antenna tuning coil *a* is assisted in performing its duty of tuning the antenna circuit by the series variable condenser *b*. The coil *a* must have turns enough to permit of tuning to the highest wave-length signals that it is desired to receive. The contact device on the coil *a*, as made by one manufacturer, has a double movable arm that makes contact with two of the coil taps so as always to leave one inactive coil tap between the two active terminals. This extra contact short-circuits part of the coil on itself by connecting two taps together. The short-circuited part of the coil tends to prevent oscillations in the radio-frequency amplifier circuit, and otherwise stabilizes operation.

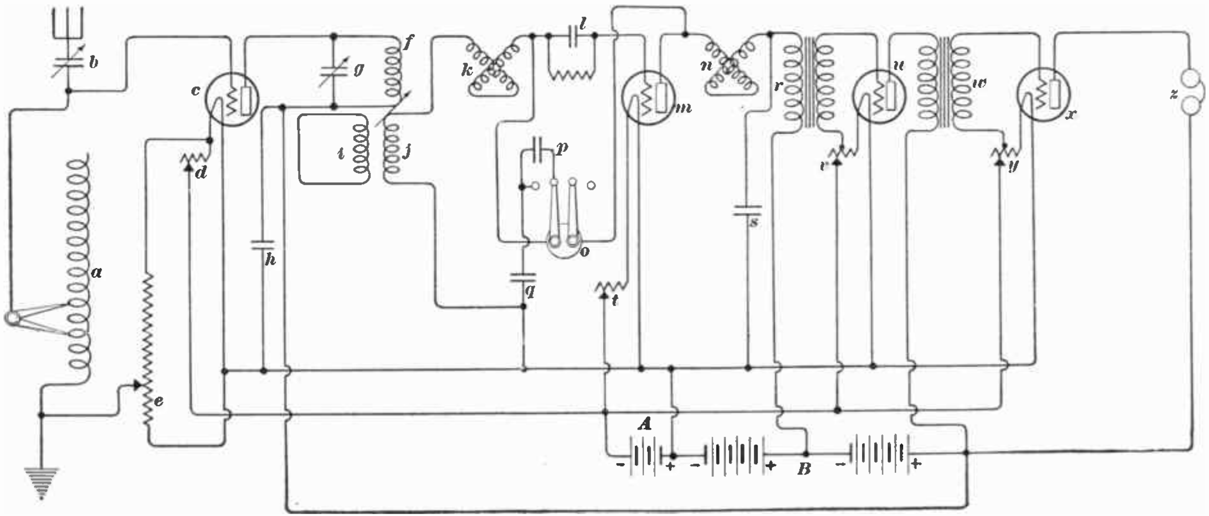


Fig. 14

From the coil *a* the signal passes to the grid of the radio-frequency amplifier tube *c*, which amplifies the signal to an extent dependent on the characteristics of the tube. The filament current of the tube *c* is controlled by the rheostat *d*. A potentiometer *e* is connected across the *A* battery and allows of adjusting the grid bias to any voltage value over the range provided by the filament battery.

51. The main output from the plate circuit of the tube *c*, Fig. 14, is through the coil *f*. This coil is tuned to the desired signal by the variable shunt condenser *g*. A rather large condenser is necessary unless output coils of various sizes are substituted to cover the desired wave-length range. A small by-pass condenser *h* affords a good path for radio-frequency currents around the *B* battery, which might offer considerable resistance to the passage of such currents.

The coil *i* is the one that normally forms the antenna or primary winding of the set. Its effect on the circuit in this case is reduced by a connection that forms a short-circuit between the coil terminals. The coil *j*, which is normally the secondary of the variocoupler, acts now as a secondary to receive energy from the output coil *f*. The coil *f* is connected with fairly long lead wires so it may be placed in the best position with respect to the coil *j* for the maximum transfer of energy. The secondary circuit also includes the variometer *k*, which is an important tuning element by virtue of its variable inductance.

The grid condenser and grid leak *l* aid the tube *m* to operate as a detector. The detector is made regenerative by the plate variometer *n*, which tunes the plate circuit. A special switch *o* has two separate contact arms which may be connected to two different circuits. Contact pins make contact with the switch arms in various positions and by that means connect the condensers *p* and *q* in the circuit for tuning the set to signals of other wave-lengths. When in the right-hand position, both contact arms rest on pins that are inactive, so all the tuning of the secondary coil *j* is done by the variometer *k*, and over a certain limited band of short wave-lengths. When the switch is in the intermediate position, as shown in the figure, the right-hand switch arm is still inactive, but the left arm completes a circuit through the condensers *p* and *q* in series. This has the effect of increasing the wave-length range of the tuner by placing the condensers across the combined inductance of the coil *j* and the variometer *k*. As the switch *o* is moved to its extreme left-hand position, two circuit connections are made by the contact arms. One connection is from the plate circuit through the right-hand switch arm and through the condenser *p* to the circuit between the variometer *k* and the grid condenser *l*. The condenser *p* acts as an auxiliary feed-back from the plate to the grid circuit on long wave-lengths, but still leaves the plate variometer *n* to control the regeneration. The other connection, through the left switch arm, places the condenser *q* across the inductance coil *j* and the variometer *k* and permits of tuning the secondary to signals of still longer wave-lengths. The movements of the condenser switch arms used here, apply to the circuit connections rather than to the movement of the dial on the panel of commercial sets. The movement of the dial on commercial sets is usually indicated by means of an arrow and proper notation.

52. The audio-frequency signal next passes to the primary winding of the audio-frequency transformer *r*, Fig. 14. The plate voltage on the detector tubes is often less than on amplifier tubes, hence a special connection is made so that only a part of the available voltage is applied to the plate of the tube *m*. A by-pass condenser *s* forms a path for the radio-frequency currents around the primary winding of the transformer *r*. A rheostat *t* is provided to control the filament current of the detector tube.

The transformer *r* transfers the audio-frequency energy in the primary winding to the secondary by transformer action, from which the energy is impressed on the grid of the audio-frequency amplifier tube *u*. This tube also has an individual rheostat *v*, which, like the others, should be able to control the filament current of the various types of tubes. This control is often accomplished by having extra fixed resistance units made up in combinations to suit different types of tubes. The grid return connection is made part way along the rheostat to secure a grid bias voltage, although more bias would be obtained by making the connection to the negative *A* battery lead.

The tube *u* amplifies the signal and sends it through the audio-frequency transformer *w*, from which it passes to the tube *x* for further amplification at audio frequency. The rheostat *y* is connected so as to control the filament current of the tube *x* and also to provide a bias on the grid of that tube through the grid-return connection. The tube *x* delivers the audio-frequency current variations to the telephone receivers, or loud speaker *z*, which renders the signal audible. The *A* and *B* batteries should be of suitable size and type to operate the tubes in a satisfactory manner.

CONDENSER TUNED TRANSFORMER COUPLING

53. Another method of coupling one stage of tuned radio-frequency amplification to a standard type of receiving set is shown in Fig. 15. In addition to illustrating a different method of coupling, this figure shows the connections for a different type of radio-frequency amplifier, especially in the coupling of the circuits. The main antenna coil *a* should have about 80 turns, and should be tapped every three to five turns over the entire working range. If a variable condenser is placed in series in the antenna circuit it will also aid in securing selectivity in tuning. The tuning coil *a*, that feeds energy to the amplifier tube *b*, need not have so many taps when a series antenna condenser is used. The potentiometer *c* will help control the tendency of the radio-frequency amplifier to oscillate.

The incoming signal to which the set is tuned, is next impressed on the grid of the amplifier tube *b*. After being amplified, the signal passes to the transformer *d*, whose windings are the primary and secondary of the variocoupler forming part of the regular set. In practice, and with this circuit, it is generally convenient and satisfactory to leave all the primary turns connected in the circuit all the time. With a sepa-

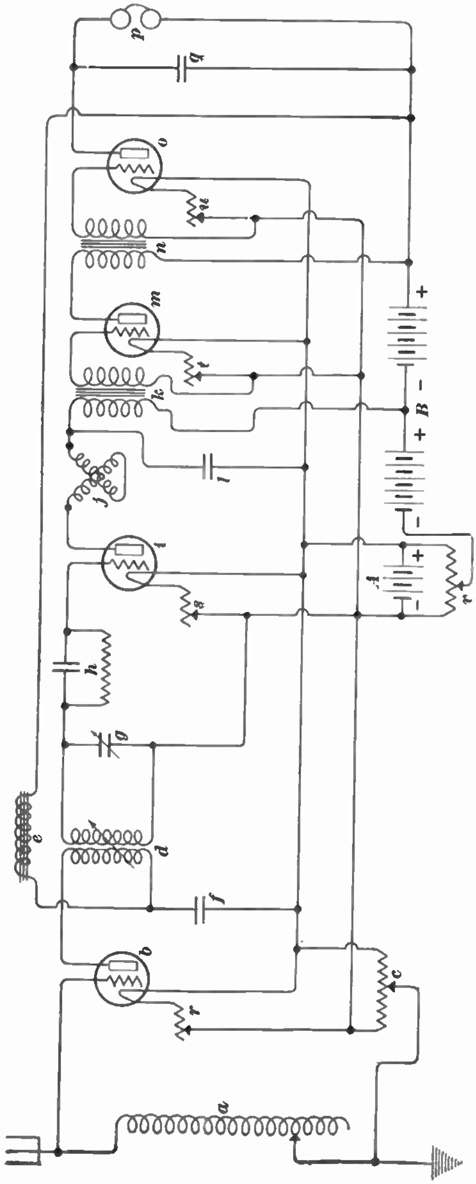


Fig. 15

rate *B* battery for the radio-frequency stage, the battery would be connected between the coil *d* and the positive filament battery lead. When the regular *B* battery is used, it is well to connect the impedance coil *e* in the battery lead. This coil will tend to prevent radio-frequency currents from passing indirectly into the regular set, where these currents might cause trouble. In order to complete the plate-circuit path for radio-frequency currents, it is necessary to use a small condenser *f* between the primary coil of the transformer *d* and the filament lead. This need not have a large capacity to work well, say about .001 microfarad. In some cases the omission of the choke coil has had no harmful effect on the operation of the additional stage.

54. The secondary of the radio-frequency transformer is the secondary of the rotor of the variocoupler *d*, Fig. 15. This winding is tuned to the desired signal by the shunt condenser *g*. The signal then passes to the grid condenser *h*, which should have a capacity close to .00025 microfarad, or at most not over .0005 microfarad. With a soft, or gassy, tube as the detector tube *i*, there is sufficient leakage of electrons from the grid so that a grid leak is not necessary. The gassy tube also works best with the grid-return connection made to the negative terminal of the *A* battery as shown in the figure. With a hard, or high-vacuum, tube the changes that should be made are, a grid leak should be connected across the grid condenser *h*, and the grid-return wire should be connected to the positive *A*-battery lead.

The plate circuit includes the variometer *j*, which serves to tune the plate circuit to resonance with the grid circuit. This regenerative feature is of use whether or not an extra stage of radio-frequency amplification is connected. The next transformer *k* is one for audio frequency since most of the signal was reduced to audio frequency by the detector tube *i*. In order to accommodate the radio-frequency currents in the plate circuit, which are fed back into the grid by regenerative action, it is important to connect a small by-pass condenser *l* across the primary of the transformer *k*.

The signal next passes to the audio-frequency amplifier tube *m* where it is amplified and sent to the transformer *n*. This transformer is likewise designed for audio-frequency operation, so, like the transformer *k*, has an iron core. The audio-frequency current is still further amplified as it passes through the three-element tube *o*. The audio-frequency current next goes to the telephone receivers *p*, where it is rendered audible. A fair-sized condenser *q*, about .001 microfarad, often helps to improve the action of the telephone receivers across which it is connected. The individual rheostats *r*, *s*, *t*, and *u* control the filament current and voltage of the four tubes. In most commercial sets, jacks or some other means are provided for ready connection of the telephone receivers to the output or plate circuit of the detector or either of the audio-frequency amplifier tubes.

55. The *A* battery, Fig. 15, should be of a size suitable to operate the particular tubes employed in the various positions. The *B*-battery voltage should also depend on the type of tube and the recommendations of the manufacturer of the tubes. With a soft, or gassy, detector tube which has been considered, there is one particular plate voltage at which operation will be best. This value is rather critical and often varies between 16 and 21 volts. A fairly easy way to secure this adjustment is by connecting the negative *B*-battery lead to an extra potentiometer *v* across the *A* battery. It is not possible to use one potentiometer to replace the potentiometers *c* and *v*, as the function of each is different. With hard, or high vacuum, tubes the potentiometer *v* will not have any appreciable effect, and should be left with the slider clear to the positive end of its range. Instead of the potentiometer, with gassy tubes, the adjustments may be made by connecting the plate lead from the detector tube to the proper voltage tap on the *B* battery.

Although none is shown in the figure, a condenser might help if connected between the grid return of the radio-frequency tube *b* and the negative terminal of the *A* battery. A condenser across the *B* battery often helps maintain quietness of operation of a set, especially as the *B* batteries become old.

FIXED TRANSFORMER COUPLING

56. A combination of a tuner with both radio- and audio-frequency application that has been used by one company may, with modifications, be adapted to other similar sets. Some tuning arrangements may appear to work best with certain types of amplifiers, but it is generally possible to utilize some form of radio-frequency amplification with a standard type of set. In the two receiving sets that have just been described some tuning was accomplished by the added radio-frequency stage, and some further selectivity was secured in the regular manner by tuning the main set to the desired signal. The receiving set of Fig. 16 performs all of the tuning operations before the desired signal is supplied to any of the radio-frequency amplifier tubes. The desired signal then passes directly

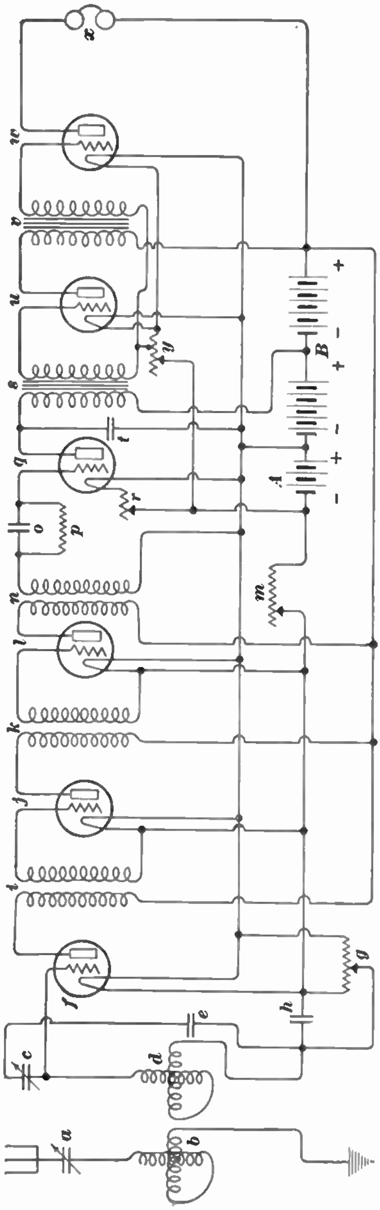


Fig. 16

through the radio-frequency amplifier tubes, the detector, the audio-frequency amplifier, and then into the telephone receivers or loud speaker.

57. The antenna tuning is accomplished by the variable condenser *a*, Fig. 16, and the variometer or variable inductance *b*. If properly proportioned and adjusted, the condenser may be mounted directly on the variometer shaft and be adjustable with it. Here, as elsewhere, the resistance of the antenna circuit should be kept as low as possible as an aid to securing selectivity in tuning the set. The variable condenser *c* and the variometer *d* are similar, in this case, to the corresponding devices in the antenna circuit. A separate fixed condenser *e* must be used in connection with the condenser *c* and the variometer *d* to give them the proper wave-length range. A fixed condenser *e* of .005 microfarad will generally be right for receivers designed to operate over the wave-length range from 200 to 600 meters. All the tuning is accomplished in the parts of the circuits that have just been described.

The radio-frequency energy is now impressed on the grid of the first radio-frequency amplifier tube *f*. In order to control the tendency of the radio-frequency amplifier to oscillate, the grid-return connection is made to the slider of a potentiometer *g*. This potentiometer is connected across the *A* battery and serves to bias the tube *f* enough to prevent oscillations in the radio-frequency amplifier. This also tends to cause operation near the correct part of the tube's characteristic curve by applying a fixed bias or steady voltage on the grid. The fixed condenser *h*, of .01 microfarad capacity, or larger, acts as a by-pass for radio-frequency currents around whatever part of the potentiometer resistance might be included in the grid-return circuit.

After amplification by the tube *f* the radio-frequency signal passes to the radio-frequency transformer *i*. This may be of any of the standard types designed for radio-frequency operation. The main requirement is that it shall be capable of operating well over the wave-length range covered by the main tuner. The tube *j* next receives the signal and sends it on to another radio-frequency transformer *k*. This transformer acts in the usual manner to transfer the energy from its primary winding to the secondary coil, from which coil it is impressed on the grid of tube *l*. The filament control of all three radio-frequency tubes *f*, *j*, and *l* is vested in the one rheostat *m*. Separate rheostats could be used for each tube, but such a refinement is not necessary in a radio-frequency amplifier.

58. The radio-frequency transformer *n*, Fig. 16, impresses the radio-frequency energy on the grid condenser *o* and grid leak *p*. The grid condenser and leak combination acting on the grid of the tube *q* causes it to act as a detector of the received radio-frequency energy. The detector tube renders the signal audible in its plate circuit, and it may be sent through telephone receivers or further amplified to secure a still stronger signal. When operated as a detector, soft, or gassy, tubes are very sensitive to adjustments of filament current, and even hard, or high vacuum, tubes are quite critical of adjustment. A separate rheostat *r* gives accurate filament control of the detector tube only. A special lead is run to the *B* battery, where connection is made with the tap to give the proper plate voltage for the detector tube.

The transformer *s* is designed for audio-frequency operation since it handles only the rectified signal from the detector tube. A by-pass condenser *t* assists in the successful operation of the detector tube and its auxiliary apparatus. The output from the transformer *s* is impressed on the grid of tube *u*, which amplifies the signal at audio frequency. The audio-frequency transformer *v* next receives the signal and passes it on to the last amplifier tube *w*. The audio-frequency current is now sent through the telephone receivers *x* to produce audible signals. In most cases the signal will be strong enough to operate a loud speaker, which would be connected in place of the telephone receivers. A small by-pass condenser might help clear up the signal if connected across the telephone receivers. A fairly large condenser, about .5 microfarad, or larger, could be connected as a by-pass, especially for the radio-frequency currents around the *B* battery. One rheostat *y* is connected so as to control the filament current to both of the audio-frequency amplifier tubes *u* and *w*. The grid-return wires from these two tubes are connected to the rheostat *y* so that a small grid bias will be applied to the audio-frequency amplifier tubes. This connection may be made so as to include either part or all of the voltage drop in the rheostat. This feature and that of a *C* battery are discussed in detail in another Section.

CONSTRUCTIONAL HINTS

CONDENSER COUPLING

59. A very small condenser will act as a fairly good coupling device between circuits to currents at radio frequencies. Parallel wires often have enough capacity effect to cause detrimental coupling between circuits one or both of which carry radio-frequency currents. It is of prime importance in constructing a radio-frequency amplifier, so to place all wires that may carry radio-frequency currents that they can have no capacity or coupling effects that might be injurious. This is accomplished by keeping all wiring as far apart as possible, and running wires at right angles where they come close together.

SOLDERED JOINTS

60. Resistance in a radio-frequency circuit tends to broaden the tuning of that circuit, so is often objectionable for that reason. Resistance causes losses with currents of any frequency, so should be avoided as much as possible under all circumstances. Good soldering tends to reduce the resistance at connection points, and also assures a permanent low-resistance contact. It is very desirable to use rosin as a soldering flux instead of acid or paste fluxes, but if the latter are used all traces of superfluous material should be removed after soldering.

POSITION OF TRANSFORMERS

61. The physical position of the transformers in a radio-frequency amplifier is of considerable importance. Some iron-core transformers have a very small external magnetic field so do not have much tendency to produce detrimental coupling effects with each other or with other parts of the circuit. Air-core transformers are very apt to have coupling effects with each other or with other parts of the circuit which may cause radio-frequency oscillations. The grid and other relatively high-potential and high-frequency connections should be well protected from undesired coupling and capacity effects.

POTENTIOMETER EFFECTS

62. Potentiometers in the grid return will often enable one to control the tendency of a radio-frequency amplifier to oscillate. The introduction of a potentiometer and some other types of stabilizing devices, particularly resistances, is apt to produce unnecessary losses of energy. The use of a potentiometer is justified in connection with gassy, or soft, detector tubes to modify the plate voltage, as some such control is essential to best operation of this type of tube.

TUBE EFFECTS

63. Any of the standard types of commercial three-element amplifier tubes will work well in radio-frequency amplifier sets. The tube possessing the better amplifying properties will generally give the more satisfactory results in actual practice. This is especially true with one-to-one ratio coupling transformers, as practically all the amplification must be secured by the tubes themselves.

Since a negative grid bias decreases the plate current and reduces the drain on the *B* battery, it is always well to use a *C* battery when possible. As has been mentioned, some types of radio-frequency amplifiers are so balanced that there is no tendency to oscillate. In such sets a considerable saving will be effected by the addition of a *C* battery so as to place a negative voltage bias on all the amplifier tubes. The amount of bias potential to use will depend upon the type of tube and the plate voltage; the manufacturer's recommendations should be followed as to the grid bias to use on all amplifier tubes. Slight variations in different tubes of any one type will sometimes cause a set of tubes to work better in one particular sequence or combination, so it is well to try them in different relative positions.

TUNING SUGGESTIONS

64. The manufacturer's advice should be sought and followed as to the best method of tuning a radio-frequency amplifier set. If such directions are not available, tuning can generally be effected by testing with the signals of a strong local sending station. With this as an aid it should be possible to study the effect of the various controls or adjustments and become familiar with their operation. Then the wave-length adjustment may be changed by small amounts to receive the signals from other transmitting stations.

Some types of sets may be tuned to various wave-length signals furnished by a buzzer-excited wavemeter coupled to the set. If the various dial settings are recorded it should be possible to tune the set closely to receive signals on any desired wave-length. Where there are several stages of radio-frequency amplification, each of which is rather critical, it is frequently most convenient to connect the antenna to the detector input circuit and see that that stage is working properly. The input can then be carried from stage to stage, away from the detector tube, making sure that each additional tube and its auxiliary circuit are operating satisfactorily before going to the next position. Radio-frequency amplification added to a standard receiving set should not materially alter the wave-length settings of that set. It would be possible to adjust the set to the desired wave-length and then tune the radio-frequency amplifier unit to the desired signals.

AUDIO-FREQUENCY AMPLIFICATION

AUDIO-FREQUENCY AMPLIFIERS

USE OF AMPLIFIERS

1. Amplification of audio-frequency signals is one of the important applications of the three-element tube. The rather weak signals, generally capable of operating telephone receivers, may be increased in strength, at audio frequency, enough to operate a loud speaker. Naturally this must be accomplished without the introduction of distortion in any form to alter the signal.

In the commercial field, audio-frequency amplifiers have considerable usefulness in long-distance land telephoning where the amplifiers, called repeaters, are installed at certain intervals to strengthen the voice currents. Such amplifiers are also used to strengthen the volume and increase the range of a speaker's voice. Many audio-frequency amplifiers are used in various types of work where it is desired to increase a very minute current or voltage change, especially for measurement purposes. Such amplifiers are also necessary, possibly in modified form, in broadcasting and transmitting stations to increase the voice currents before they are impressed on the radio-frequency currents and sent out as radio signals.

TRANSFORMER-COUPLED AMPLIFIERS

GENERAL FEATURES

2. The transformer method of coupling amplifier tubes is the best method that has been devised for this work. A transformer forms an economical and reliable method of intertube coupling, and when properly designed and installed will introduce very little distortion into the set. A transformer has an inductive winding and considerable distributed capacity, so it tends to have a natural resonance period of its own. If properly designed the resonance point of the transformer is not pronounced and will not appreciably affect the operation.

The primary winding of a transformer is the one connected in the plate or other circuit that feeds into the transformer. This primary winding should have an impedance fairly close to that of the plate impedance of the tube from which it receives energy. When this condition obtains, the output from the tube is a maximum with the other dependent factors properly adjusted. The wire used in the transformers should be of a size capable of carrying the steady plate current of the preceding tube and the incoming signal current. The output, or secondary, winding receives the signal variations by transformer action from the primary coil and impresses these pulsations on the grid of the succeeding tube. The signal is then amplified as it passes through the tube and is made to operate a loud speaker or it may be still further amplified before reproduction as an audible signal.

3. The output of a three-element tube, when used as an amplifier, depends on the voltage applied to the grid, with other factors properly adjusted; that is, the output energy, manifest by the volume of signal, increases with an increase of the potential variation applied to the grid. This increase is practically independent of the available current or power in the grid circuit except as this current may hinder operation under improper conditions. Since a high voltage is what is desired, it is possible to design the transformer windings with a step-up voltage ratio. Thus, if there are five times as many turns of wire on the secondary winding as there are in the primary, the voltage induced in the secondary will be approximately five times as great as that in the primary winding. This higher potential signal will give a correspondingly greater output energy from the tube than would have been the case with a one-to-one turn ratio in the transformer.

A turn ratio between the primary and secondary windings of one to four is about the best for general application. Some manufacturers and operators recommend an even lower ratio, say, one to three, or, also, one to three and one-half. Values lower than these are not common, but are frequently used in special cases. The lower-ratio transformers are recommended in all stages of an amplifier, with the exception that one with a higher ratio will frequently prove more suitable in the first stage. Any transformer tends to introduce distortion, and this tendency is generally aggravated with a high turn ratio. For this reason, as well as others, a high turn ratio for a transformer is not desirable. However, there will be very little distortion introduced by a transformer with a relatively high turn ratio, say one to seven, if it is used in the first stage or step of an amplifier. Transformers with a turn ratio of one to five are very common in commercial practice, and many of them operate with very little distortion.

ONE-STAGE AUDIO-FREQUENCY AMPLIFIER

4. One stage or step of audio-frequency amplification when added to a common-type receiving tuner will not in most cases bring in signals or amplify them, sufficiently to operate a loud speaker. However, a large antenna and a favorable location will frequently permit of loud-speaker operation with only one stage of audio-frequency amplification. One stage of audio-frequency amplification adds very little to a set when only head-phones are used, except in some cases where the received signal is very weak. Two stages of audio-frequency amplification are commonly installed and should give sufficient amplification to operate a loud speaker with relatively weak signal impulses in the detector tube.

An audio-frequency amplifier may be constructed as a separate unit with a complete set of *A* and *B* batteries. The amplifier may then be moved readily and its input connected with the output of any standard set where increased signal strength is desired. The amplifier unit illustrated in Fig. 1 is one that may be applied to a single-circuit tuner. The main tuning coil *a* is aided in tuning the set by the variable condenser *b*. The grid condenser *c* with its grid leak helps the detector tube *d* to change the incoming signal to an audio frequency.

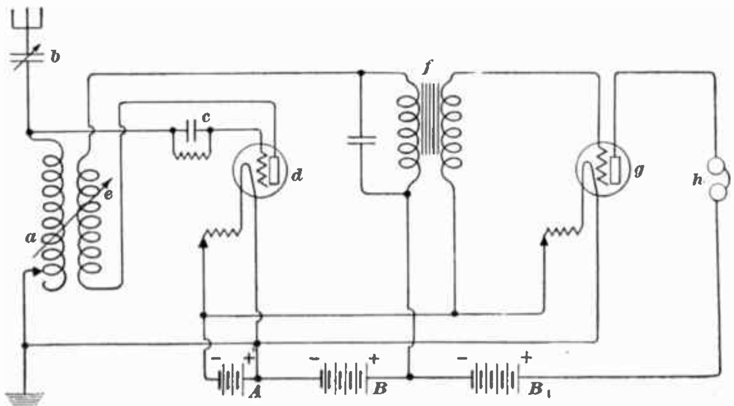


FIG. 1

The coil *e* in the plate circuit feeds energy back into the grid circuit from the plate circuit and produces regeneration. Instead of passing through telephone receivers the energy is fed into the primary winding of an audio-frequency transformer *f*. The radio-frequency currents necessary to produce regeneration could not pass through the inductive primary winding of transformer *f*, so a small shunt condenser is connected to provide a path for such currents. Plate voltage for the detector tube is supplied by the battery *B*.

5. The energy from the tube *d*, Fig. 1, is transferred by transformer action from the primary of transformer *f* to the secondary winding. From the secondary the signal is impressed on the grid of the amplifier tube *g*. The amplified signal then passes through the telephone receivers *h* to produce audible sounds, or, if the energy is of sufficient strength a loud speaker may be connected at *h*. The filament current for the amplifier tube *g* is controlled by an individual rheostat. A common *A* battery supplies the filament current for both tubes. The relatively high plate potential for the amplifier is furnished by a battery made up of the detector battery *B* with an additional battery B_1, so as to obtain the necessary operating voltage.

An amplifier tube generally requires a higher plate potential than does a detector tube, so extra battery units may be added in the amplifier plate circuit. With tubes of widely different characteristics requiring different voltages on the filaments and plates, separate *A* and *B* batteries should be used.

The grid return of the amplifier tube *g* should be wired so as to secure the voltage drop of the rheostat as a negative grid bias. This bias, with the rheostat in the negative battery lead, will suffice for moderate plate voltages. With high plate potentials a *C* battery should be connected in the grid return of the amplifier tube, the bias voltage being dependent on the amount of *B* battery voltage. The manufacturer's recommendation in this respect should be followed.

6. In a single-stage amplifier, the coupling transformer may have a fairly high turn ratio with no noticeable distortion. When separate *A* batteries are used it may stabilize the operation of the set to connect the negative terminals of the batteries together. It is perfectly feasible, if such is desired, to connect the telephone receivers directly in the plate circuit of the tube *d*, Fig. 1, or a telephone jack may be installed in the plate circuit of the detector and in the plate circuit of the amplifier tube to facilitate connection into either circuit. A telephone jack that has an extra set of contact points for filament control is also a convenience, as this automatically lights the filaments of all the tubes that are actually in use.

The type of tube to use in a single-stage amplifier is not of extreme importance, as nearly any of the standard commercial types will give good results. If the detector tube is one of the types that operates from a dry cell for filament supply, it is convenient and logical to use one of a similar type in the amplifier stage. Where a storage battery is available the amplifier tube might well be one with a larger filament and operated from the same battery. At any rate the operating voltages must be those applicable to the particular tubes actually installed.

TWO-STAGE AUDIO-FREQUENCY AMPLIFIER

7. A two-stage audio-frequency amplifier is very common and is quite easy to construct. Two stages or steps of audio-frequency amplification should give sufficient output signal strength to operate a loud speaker even with fairly weak signals in the detector tube. A two-stage amplifier set may be assembled with reasonable ease, and with good transformers there should be little trouble from distortion or a persistent tendency to oscillate.

In Fig. 2 is shown a conventional two-stage audio-frequency amplifier directly combined with a standard type of receiver unit. The antenna to ground circuit is tuned by taps on the main tuning coil *a* and the variable condenser *b*. The secondary coil *c* is tuned by the shunt variable condenser *d*. A grid condenser *e* with its grid leak performs the usual function of aiding the tube *f* to act as a detector of the radio-frequency signals. The filament rheostat for the detector tube should have a vernier adjustment for fine tuning.

The plate circuit of the detector tube *f* has a variometer *g* to produce a stronger signal by regeneration. The primary of the audio-frequency transformer *h* is connected in the plate circuit of the detector tube by contacts in jack *i* that are usually closed. By inserting a telephone plug into the jack *i* it is possible to connect a pair of telephone receivers directly into the detector-tube plate circuit. No gain is secured by applying a high voltage such as an amplifier tube can stand, to the plate of the detector tube, so a special lead is run to a rather low voltage tap on the *B* battery. A small fixed condenser *j* acts as a by-pass for radio-frequency currents, which would otherwise be weakened in their passage through the trans-

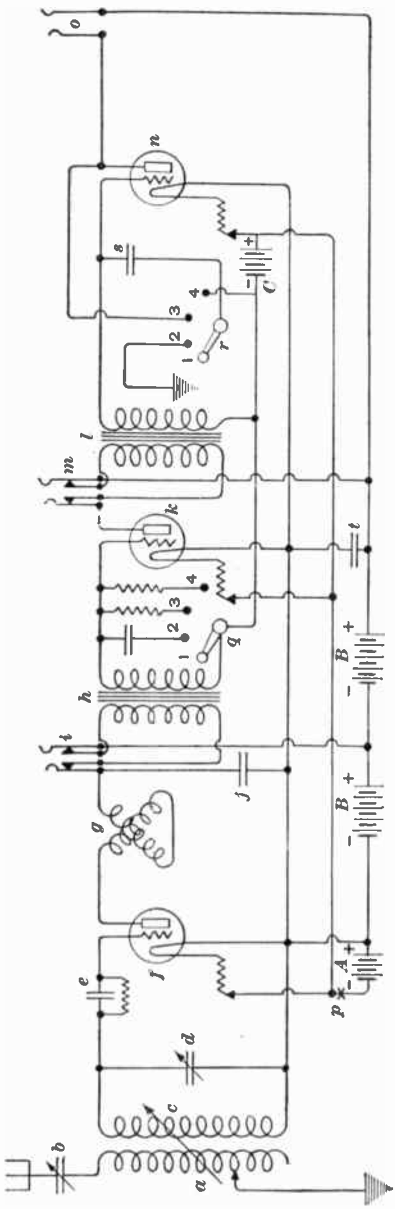


FIG. 2

former, or receivers, and the *B* battery. The *A* battery should be capable of supplying energy to the filaments of all the tubes in the set.

8. The secondary of the transformer *h*, Fig. 2, impresses the signal on the grid of the first amplifier tube *k*. After the signal is strengthened by the amplifier tube *k*, it passes through another audio-frequency transformer *l*. A telephone jack *m* enables a set of telephone receivers or a loud speaker to be connected in the plate circuit of the first amplifier tube; this operation automatically disconnects the transformer from the plate circuit.

The transformer *l* steps up the voltage of any signal it receives and impresses it on the grid of the second amplifier tube *n*. This tube still further amplifies the signal at audio frequency. A jack at *o* permits of plugging in a loud speaker or telephone receivers at this point or in the plate circuits of the preceding tubes by the jacks that are provided. The detector and amplifier tubes have individual rheostats, so that only the tubes that are actually in use need be turned on. Thus, with the telephone receivers connected in the plate circuit of tube *f*, the amplifier tubes *k* and *n* are not operative and their filament circuits should be opened by their filament rheostats. A small battery circuit switch at *p* is a convenience in opening and closing the filament circuit without turning the various filament rheostats.

9. The *A*, or filament battery, Fig. 2, may be of any suitable type capable of operating the three tubes in the set. In general, a storage battery will give the better results, but it also has several disadvantages as compared with a dry-cell *A*-battery supply. The *B* battery is conventionally made of special small dry cells conveniently grouped in units. The output signal, in general, will be stronger the higher the plate voltage applied to the amplifier tubes. Care should be taken, nevertheless, not to exceed the maximum rated plate voltage of the tubes. Chiefly to eliminate distortion, but also to reduce the plate current, a *C* battery should be connected as shown by the diagram, especially with the higher plate potentials. As indicated, the *C* battery is connected in the grid-return lead so as to apply a negative bias voltage to the grids of the amplifier tubes. There is no appreciable current taken from the *C* battery, hence it may be made of a few small dry cells connected in series to give the required value.

10. Several features have been incorporated in this amplifier, Fig. 2, that are conducive to quietness and stability of operation. Across the secondary winding of the transformer *h* is connected a switch arm *q* that may make contact with any one of the contact points *1*, *2*, *3*, and *4*. When the switch arm rests on contact *1* there is no auxiliary connection made across the transformer, and the switch has no effect. When the switch is on contact point *2* the small condenser to which it is connected is placed in circuit across the transformer secondary. This condenser may have a capacity of .00025 microfarad.

although larger or even smaller values may operate better with some sets. A small fixed mica condenser will serve the purpose.

When the switch *q* rests on contact point *3* it connects a resistance of say 100,000 ohms across the secondary winding of transformer *h*. On switch point *4* a somewhat lower resistance, possibly 25,000 ohms, is connected as a shunt path across the secondary winding. These high resistances across the transformer may decrease the output signal strength to a noticeable degree, but this is more than compensated for by the quietness of operation. Fixed grid leaks are very convenient for these units, and values other than those suggested should be tried out. Lower resistances will, in general, decrease the signal strength, but will also eliminate more of the inherent noises in the set. It is often the case that one amplifier set will work better with the shunt condenser and another will give more satisfactory service with the resistance units. It is not necessary to arrange a switch in the circuit if not desirable, as it will suffice to connect the various units in by temporary wiring, the effect of each being noted. The one that gives the desired result can then be permanently connected.

11. Another feature that frequently gives considerable improvement in the operation of an amplifier is the switch *r*, Fig. 2, that connects the condenser *s* in any one of the connections made by the contact points *1*, *2*, *3*, and *4*. The contact point labeled *1* is merely an open circuit position for the switch arm *r*, which leaves the condenser *s* out of the circuit. With the switch arm *r* on contact *2*, the condenser *s* is connected with the ground. This connection of the grid to ground through a condenser, frequently is very beneficial in an amplifier set. With the switch *r* on contact *3* the grid and plate circuits are connected together through the condenser *s*, a feature of importance in eliminating some sorts of inherent trouble. The condenser *s* is connected across the secondary of transformer *l* when the switch arm is in contact with point *4*. This condenser *s* may be fixed and of any good type that does not have much loss. Values of .00025 to .001 microfarad may be tried and the size used that gives best results.

12. One of the most important factors to watch in constructing a radio set is to note that each component part is made of high-class material. This will eliminate much trouble that otherwise may show up later. In the set under consideration, Fig. 2, it will probably aid operation to connect the *A* battery to the ground; that is, grounding the positive or else the negative; a condenser, say of 1 microfarad, connected across the two *B* batteries as shown at *t*, will tend to eliminate noises arising from the *B* batteries, especially after they have nearly run down.

The type of tubes to use in an amplifier set is not of great importance in itself, as satisfactory results may be obtained by any of the types put out by the reliable manufacturers. In general, those with a higher value of mutual conductance represent types that give the better over-all amplification. The factor of filament-current supply is also often a controlling one in determining the type of tube to use in the amplifier. A small but reliable voltmeter is a great convenience in setting the tubes to the proper operating filament temperature. A small switch arrangement may be devised for connecting the voltmeter across any one of the tube filaments while they are being adjusted. It is good practice to try interchanging the tubes among the various stages until the combination is found that works best. The last tube may be placed in the first socket and all the other tubes moved to the succeeding sockets. When a large output from the loud speaker is desired, a type of tube designed for such service will give stronger signals with less distortion.

The transformers may be of any good reliable make. A low ratio of turns is often best in a two-stage amplifier, say a ratio of 1 to 4½. Exceptionally good results have been obtained by at least one manufacturer who recommends a turn ratio of 1 to 3½ in both stages of a two-step amplifier. If properly installed, a higher-ratio transformer may be used successfully in the first stage. Connection of the iron cores of the transformers to the negative filament lead or to the ground, is often very effective in reducing the tendency of an amplifier to oscillate or set up extraneous noises.

13. The plate circuit of a tube forms a local circuit made up of the impedance of the tube, the resistance and inductance of the transformer primary, and the *B* battery. If the direct-current resistance of all these elements is fairly low, there will be a fairly large plate current. The purpose of the grid element is to control the plate current in accord with the signals impressed on the grid. The plate-current variations produce voltage changes across the transformer windings that are of importance in determining the value of the amplifier unit. If the impedance of the tube is high, considerable energy is used up in it, that does not aid in the amplification. However, this resistance cannot be made too low or the tube will not retain its characteristic features.

If the impedance of the transformer primary is high, a rather high voltage change will be produced across it with plate-current changes. With relatively low impedance, the variation is not so great, and the output signal variation is likewise not so pronounced. A transformer possesses the advantage, not common to some other devices, of offering a relatively small opposition to the *B*-battery current, and offering a relatively high opposition to the plate-current changes, which thereby gives good amplification. The high impedance of the transformer is provided by the very large number of turns of wire closely wound on an iron core. The wire should be of such size that it does not have a large resistance.

14. Transformer coupling for an amplifier has the decided advantage that it makes good use of the available energy. The amplification per stage for good results is higher than that obtainable with most other methods. To give best results, the transformer must amplify signals of all frequencies equally well, a feature that is likely to be lacking in some transformers. This fault is caused by the fact that the impedance varies to some extent with the frequency, and is particularly noticeable at the lower frequencies. If the impedance of the current path through the winding of the transformer is made relatively high, the amplification of signals will be more nearly equal over the useful band of frequencies.

In actual transformers it is necessary, in many types, to connect the outside end of the primary to the plate element, and the outside end of the secondary winding to the grid of the next tube. If the ends are not labeled, the proper way to connect them may be determined by experiment.

THREE-STAGE AUDIO-FREQUENCY AMPLIFIER

15. Three-stage audio-frequency amplifiers are sometimes made with transformer coupling, although this method is not commonly followed. Such an amplifier is shown in Fig. 3 where, with the detector, a total of four tubes is required. The circuit arrangement of the first tube *a* is the conventional three-circuit tuner. A variometer *b* in the plate circuit mákes the three-circuit tuning element regenerative. Other types of tuning elements might be used instead of the typical three-circuit tuner illustrated here.

The first audio-frequency transformer *c* receives the signal at audio frequency from the detector tube *a*. From the transformer *c* the signal is impressed on the grid of the amplifier tube *d*. The transformer *e* next receives the signal and after stepping up the voltage, feeds it to the amplifier tube *f*. The signal is next sent through the third amplifier stage comprising the transformer *g* and the tube *h*. From here the signal may be sent through a loud speaker, which may be connected through the jack *i*.

16. The *A* and *B* batteries, Fig. 3, are of any suitable type capable of operating the four tubes for a reasonable length of time. A grid, or *C*, battery should be connected as shown so as to apply a negative grid bias to all the amplifier tubes. A rather large condenser at *j* often assists in eliminating noises arising from defective *B* batteries. It is often a convenience to connect jacks in each stage in the plate circuit to facilitate connection to any part of the circuit. Then, if all the amplifier steps are not needed, only those necessary may be used when listening to a local station, while the three stages will be available for amplifying the weaker signals from distant stations.

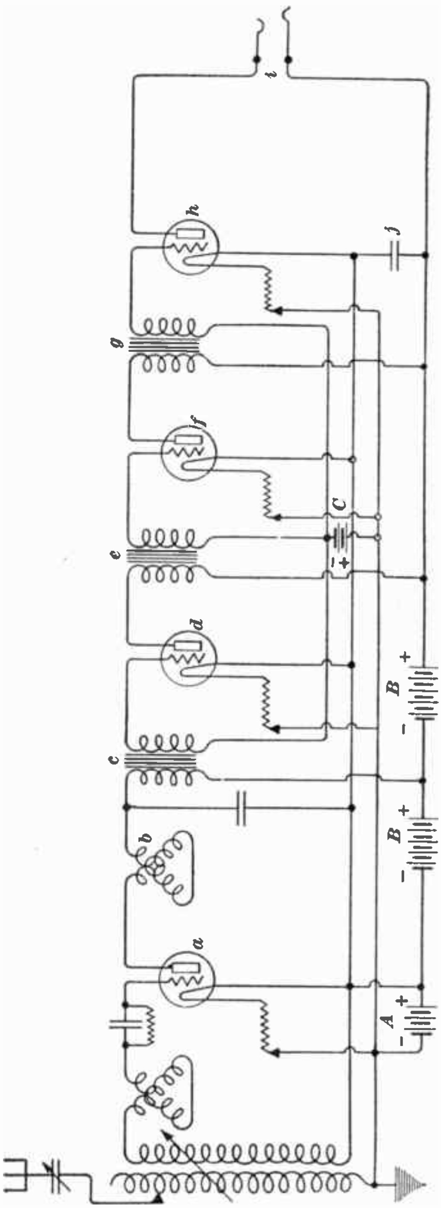


FIG. 3

The transformers in a three-stage audio-frequency amplifier should all have a low ratio of turns. A high turn ratio, especially in three steps, is very likely to cause oscillations to be set up between the various transformers and thus drown out the desired signal. Some of the remedies described elsewhere in this Section may be applied if there is a persistent tendency to oscillate. Metal shields or separators between the various stages should help remove any such tendency.

Any of the standard tubes should give good results in a three-stage amplifier. The usual receiving type of tubes will generally give all the output desired, but where exceptionally strong signals are required, it is possible to use some of the low-powered transmitting tubes, especially in the last, or third, stage. Such transmitting tubes, in general, require a larger amount of energy in the filament and plate circuits, but should give a correspondingly greater audible signal output with less distortion.

PUSH-PULL AMPLIFIER

17. Principle of Operation.—The amplification of audio-frequency signals presents many complex problems. The design and construction of the apparatus entering into an amplifier affect greatly the volume and quality of the resultant audible signal. The amplifier tubes themselves have their limitations. When overloaded, the tubes may distort the signals to such an extent that these are hardly recognizable. This form of distortion can usually be remedied by using any of the special amplifier tubes, power tubes, or by connecting two or more tubes in parallel so as to divide the load between the several tubes.

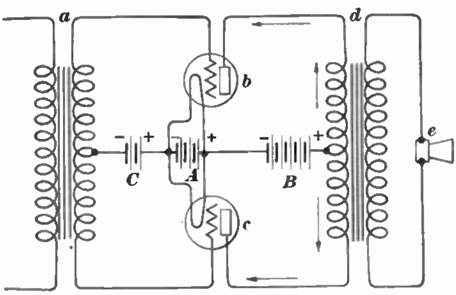


Fig. 4

A refinement of a multiple tube connection for amplifying audio-frequency signals is found in the *push-pull amplifier*, a simple diagram of which is shown in Fig. 4. The set consists essentially of a special input transformer *a*, which supplies the energy that is amplified by the tubes *b* and *c*, and an output transformer *d*, which collects the combined load of the two tubes and delivers it to the loud speaker *e*. Both the input transformer *a* and the output transformer *d* are of special construction, differing from other transformers mainly in the fact that each of them has an additional terminal, which is connected to the mid-point of one of the windings.

18. The primary winding of the transformer *a* is connected in the plate circuit of the preceding detector or amplifier tube. The secondary winding has three terminals; each of the end terminals is connected to the grid of one of the tubes, and the terminal from the mid-point of the winding is connected to a common filament terminal of the tubes through a *C* battery. Voltage variations induced in the secondary winding of the transformer *a* are effective in the grid circuits of the tubes *b* and *c*. When the direction of the voltage is such as to give the grid of the tube *b* a positive charge, the grid of the tube *c* will have a negative charge. The current in the plate circuit of tube *b* therefore increases while that of tube *c* decreases. The current variations in the plate circuit of each will be as shown in Fig. 5 (*a*). The curve *a* is that of the current in the plate circuit of tube *b*, Fig. 4, and the curve *b*, Fig. 5 (*a*), gives the corresponding value of the plate current of tube *c*, Fig. 4. It should be noted that as the current curve *a*, Fig. 5 (*a*), moves farther away from the zero line, or increases in value, the curve *b* moves nearer the zero line, or decreases in value. The two currents have a cumulative effect, so that the resultant current may be considered that of Fig. 5. (*b*). The current represented in view (*b*) is the one that is really effective in the loud-speaker circuit of Fig. 4. The amplitude of the current changes on either side of the zero line in Fig. 5 (*b*) is practically as large as that of the change in the individual currents shown in view (*a*), but the variation of the current from maximum-positive to maximum-negative condition produces a much larger variation of current in the loud-speaker circuit with a resultant louder signal and with less distortion than would be secured with a single tube. Even with dry-cell tubes the signals are sufficiently amplified and are clear enough to operate a reasonably large loud speaker.

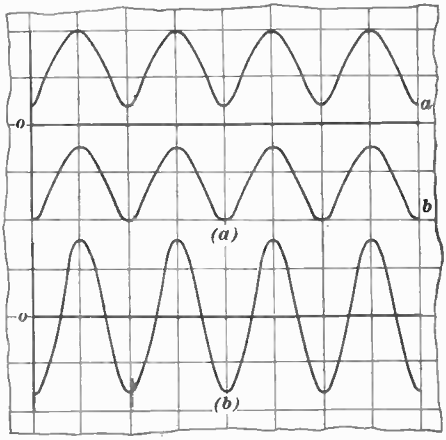


FIG. 5

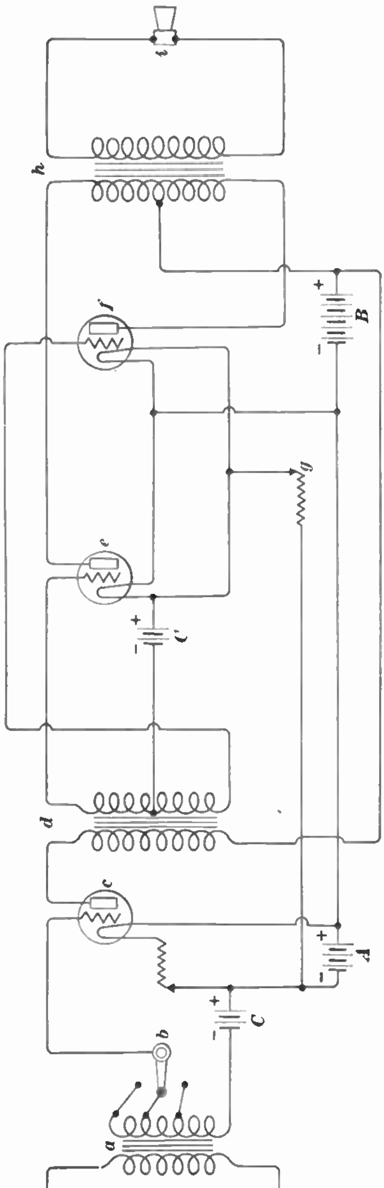


FIG. 5

19. Push-Pull Circuit. In commercial sets the push-pull amplifier usually follows after the first stage of the ordinary audio-frequency amplification. The amplified signal is then of sufficient strength to be more effectively amplified by the push-pull amplifier. In Fig. 6 the primary of the transformer *a* is connected in the plate circuit of the detector tube. The secondary coil is tapped and connections are extended to switch points, any one of which may be brought in contact with the switch arm *b*. This feature is for regulating the voltage that is impressed on the grid of the tube *c*. The switch is not always used. The output of tube *c* is passed through the transformer *d* to the two tubes *c* and *f* of the push-pull amplifier. If the two tubes are of the same type their filament currents may be controlled by the one rheostat *g*. The output of the push-pull amplifier is transferred by means of the transformer *h* to the loud speaker *i*.

20. Practically any type of tube that has a reasonably high emission will operate in a push-pull amplifier satisfactorily. Best results are generally secured with a fairly high plate voltage, and a grid bias sufficient to limit the plate current to a reasonable value. The final plate-current change will then be quite large, and will produce an output signal variation of maximum intensity. Such amplifiers are of particular value in cases where a large output is desired with a minimum of distortion.

The transformers of a push-pull amplifier do not generally have a high turn ratio, say one to two or one to three. The output, as well as the input transformer, must be specially designed for best operation with the tubes and horn that are to form parts of the set. A tendency of the set to oscillate may often be remedied by connecting a .001-microfarad condenser between one terminal of the output winding, or secondary, of transformer *h* and the grid of one of the push-pull tubes. Or, a direct connection may help if made from this same secondary terminal to the negative filament terminal, or to the ground if the *A* battery is not grounded.

RESISTANCE-COUPLED AMPLIFIERS

21. The resistance-coupled amplifier is one of the best audio-frequency amplifiers in so far as quality of reproduction is concerned. The unit is capable of giving good output signals without introducing an appreciable amount of distortion. It is called a resistance-coupled amplifier because resistance units are used as the coupling devices. These resistance units must be properly proportioned and used with suitable condensers for best results.

A conventional wiring diagram of a resistance-coupled amplifier is given in Fig. 7. The primary coil of a variocoupler is shown at *a* and the secondary coil at *b*. The circuit is tuned by the condenser across the secondary coil *b*, but some other form of tuner may be used. The output from a radio-frequency amplifier may be used. The grid condenser *c* with its grid leak performs its usual action in conjunction with the

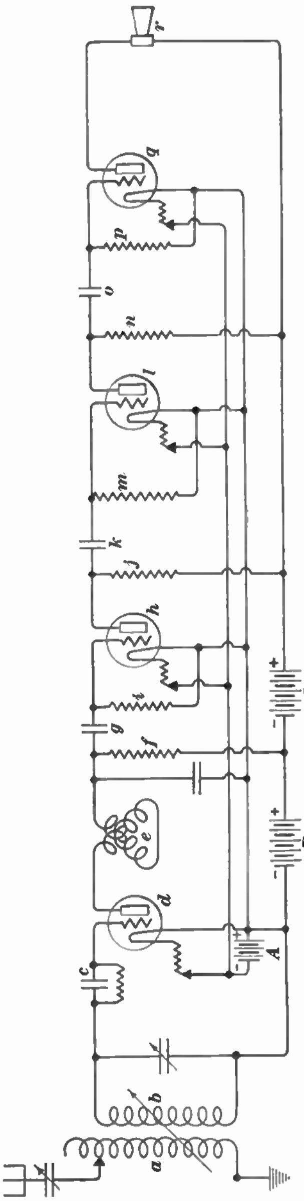


FIG. 7

detector tube *d*. A variometer *c* tunes the plate circuit to make the set more sensitive by introducing regeneration. The resistance unit *f* forms part of the plate circuit of the detector tube. Any voltage changes produced by plate-current variations in resistance *f* are impressed through the condenser *g* on the grid of tube *h*.

22. The condenser *g*, Fig. 7, serves to insulate or isolate the grid of tube *h* from the *B* battery potential of the preceding tube *d*. If this condenser were not used no amplification could be secured owing to the high voltage that would be applied to the grid. A grid leak *i* is necessary to provide a path for electron charges, which accumulate on the grid. Otherwise, a negative charge would soon accumulate on the grid during operation, and block or prevent further operations. The amplifying power of tube *h* now comes into action to strengthen the signal.

The plate circuit of tube *h* includes the resistance unit *j* across which the signal-current variations produce voltage changes. These voltage changes are sent through condenser *k* and impressed on the grid of another amplifier tube *l*. A grid leak *m* is necessary on this tube to provide a path for negative charges to leak off the grid, which is essential to continuous operation. In a similar manner, the plate resistance *n*, coupling condenser *o*, and the grid-leak resistance *p* transfer the energy to the third amplifier tube *q*. The output from this tube should be ample to operate a loud speaker as shown at *r*.

Separate filament rheostats control the filament currents of tubes *d*, *h*, *l*, and *q*, respectively. The type of *A* battery will depend to a considerable extent on the type of tubes that are used. A separate tap is taken off the *B* battery for the lower-voltage supply required by the detector tube. No grid bias or *C* batteries are required by a resistance-coupled amplifier, since a grid bias is produced by the current in the grid leaks on the various tubes. The grid leaks may be connected to the negative filament lead if desired. The use of a *C* battery is justified if it improves the operation of the set. A connection from the negative-filament battery terminal to the ground may help quiet the operation of the whole set, especially if there are any hand-capacity effects. A small fixed condenser, of say .001-microfarad capacity, connected across the resistance *f* and part of the *B* battery, is practically a necessity in producing regeneration in the set.

23. The outstanding advantage of resistance-coupled amplifiers is the ability to amplify signals over the whole range of audio-frequencies with practically no distortion. The amplification per stage is apt to be less than that usually produced with transformer-coupled amplifiers. In this respect it is generally considered that three stages of resistance-coupled amplification are required to give signals comparable in volume with those from a two-stage transformer-coupled amplifier.

With a certain impedance in the tube, the external plate-coupling device must have a fairly high resistance so that plate-current changes will cause considerable voltage changes across this coupling resistance. That is, the higher the resistance, up to certain limits, the greater will be the output from the plate circuit. However, if this resistance is much higher than the plate-to-filament impedance, the plate current will be small, which is a condition to guard against, since this will in turn decrease the output. Or, in order to obtain a reasonable plate current it will be necessary to use an excessively high *B*-battery voltage, which is an expensive procedure. Also, if the plate voltage is not high enough, distortion will result from operation on a portion of the characteristic curve that is not straight, or nearly so.

24. Despite the apparent limitations outlined in the preceding paragraph, the values of the coupling resistances are not very critical. The resistance in the plate circuit for most American tubes should be in the range of 50,000 to 75,000 ohms, with some preference for the lower value. This resistance should be of a type that will not change in value appreciably with current changes, since this in itself would tend to introduce distortion. Lavite and some other types of non-inductive resistance units have given very good service in this field.

The coupling condenser should have a capacity close to 2 microfarads, although capacities of 1 microfarad or even smaller should work nearly as well. It is well to try grid leaks of the range of 250,000 to 2,000,000 ohms, although a resistance of 500,000 ohms is about the average generally used. In some instances some advantage has been gained by using variable grid leaks, but such should be installed with care. Plate potentials of 135 volts are very common in practice, and give excellent results. About 60 volts should be used on the detector tube to compensate for the voltage drop through the high resistance in the plate circuit.

CHOKE-COIL COUPLED AMPLIFIER

25. Another method of coupling the various tubes for audio-frequency amplification is by means of *choke coils.* The choke coils are normally connected in the plate circuit, and these coils comprise the units actually responsible for the transfer of energy, although accessory devices are necessary too. Such an amplifier is shown in conjunction with a tuner unit in

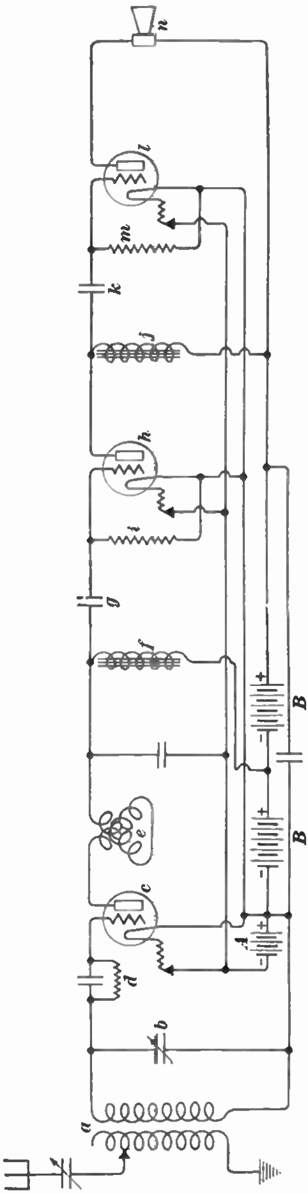


FIG. 8

Fig. 8. The tuning circuit comprises the variocoupler *a*, the secondary of which is tuned by means of the variable condenser *b*. The signal then passes to the detector tube *c*, which, with the aid of the grid condenser and leak *d*, performs its usual detecting action. The set is made regenerative for maximum signal strength by the plate variometer *e*.

The choke coil at *f* carries the plate current that passes to the detector tube *c*. Any change in this plate current causes voltage variations to be produced across this choke coil, which variations are carried through condenser *g* and impressed on the grid of the amplifier tube *h*. A grid leak at *i* forms a leakage path for charges to leave the grid of tube *h*. Another choke coil *j* acts as the coupling device through condenser *k* to the grid of tube *l*. A grid leak *m* is here also provided as was done on the other amplifier tube *h*, to permit charges to leak off the grid. The output, or amplified, signal is sent through the loud speaker *n*. A 1 microfarad fixed condenser across the *B* battery is often useful in eliminating noises in the set arising from the *B* batteries, especially after they have nearly run down.

26. The main purpose of any amplifier is to perform its function of increasing or strengthening the signal with the minimum amount of energy. The amplifier coupling units should pass a fairly large plate current without an excessive *B*-battery voltage so that the tube can function to good advantage. This coupling unit should also offer a high resistance or impedance to the signal-current pulsations so that the strength of the output signal variation may be a maximum. The choke coil performs these functions well in that it inherently offers a fairly low resistance to a direct current, such as the plate current, and a relatively high impedance to an alternating current, such as the signal current. The *B*-battery voltage required with a choke-coil coupled unit is considerably less than that required with a resistance-coupled amplifier. Unless the impedance of the choke coil is high, it will not amplify signals of different frequencies by equal amounts. This is due to the fact that the reactance of a choke coil is different for different frequencies. However, if the inductance is made quite large, the reactance will be nearly constant over the useful frequency range. The coil should have a very large number of turns, and an iron core for maximum inductance. The secondary of an audio-frequency transformer should serve very well as the main coupling unit in a choke-coil coupled amplifier.

The coupling condenser should have a rather large capacity so as not to introduce much loss or distortion into the circuit. A condenser with a capacity of about 1 or preferably 2 microfarads is therefore required, although capacities as low as .1 microfarad have given excellent results in practice. The grid leaks on the amplifier tubes may be anywhere from 200,000 ohms to 2,000,000 ohms. This resistance is ordinarily not critical, although some value may be found that will work particularly well with certain tubes. The resistance unit should be of good quality so that its value will not change while it is in use.

RADIO- AND AUDIO-FREQUENCY AMPLIFIERS

CASCADE AMPLIFIERS

INTRODUCTION

27. In the reception of radio signals, especially those from telephone broadcasting stations, an effort is made to intercept not only the strong signals from the powerful or nearby stations, but also the weaker signals from the less powerful or more distant stations. The signals from nearby stations are usually of sufficient strength, and need no preliminary amplification to operate a detector tube. After detection, these signals may be amplified at audio-frequency to any desired intensity by the methods previously outlined. Weak radio signals on the other hand, must be amplified at their original radio frequency so as to be of sufficient strength when passed on to the detector circuit. Thus both radio- and audio-frequency amplification increases the range of a receiving set while audio-frequency amplification increases the volume of the detected signals.

RADIO- AND AUDIO-FREQUENCY AMPLIFIER CIRCUITS

28. A combination of radio-frequency amplification and audio-frequency amplification with a cyrstal or vacuum-tube detector may be found in many receiving sets. The successive stages of radio-frequency and audio-frequency amplification are connected in cascade, as indicated in Fig. 9. First comes the *radio-frequency amplifier*, which may consist of one or more stages. Any one of the radio-frequency amplifier systems outlined in a previous Section may be used in this connection. For an antenna, any one of the conventional types may be used. With a loop antenna more stages of radio-frequency amplification are required than with an outdoor L- or T-type antenna, because the voltages induced in a loop antenna are much lower than those induced in a large outdoor antenna and require greater amplification to be of sufficient strength before being advanced to the detector circuit.

29. Next to the radio-frequency amplifier, Fig 9, comes the detector circuit. With a vacuum-tube detector, the connection between the detector and the radio-frequency amplifier is usually the same as between the successive stages of the radio-frequency amplifier. If the coupling between the successive amplifier stages is of the transformer type it is usual to use a transformer between the last stage of the radio-frequency amplifier and the detector. Similarly a resistance or choke-coil coupling is here used if such had been used in the radio-frequency amplifier. In many cases, however, a different form

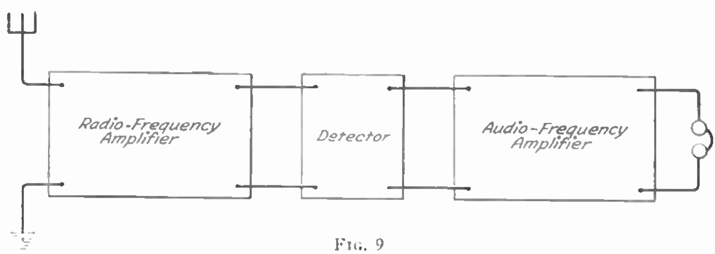


FIG. 9

of coupling is used between the detector and radio-frequency amplifier from that used between the stages of the radio-frequency amplifier. The kind of coupling depends entirely on the material available and the requirements of the circuit. The detector circuit may be arranged to be either of the regenerative or non-regenerative type. If a crystal detector is used, its circuit is usually coupled to the radio-frequency amplifier by means of a suitable radio-frequency transformer.

30. The output of the detector circuit is directed to the *audio-frequency amplifier*, Fig. 9. The amplifier may consist of any reasonable number of stages and may be constructed to suit the fancy or the need of the experimenter. If a loud speaker is to be used and a large volume of sound is desired with as little distortion as possible, it may be advisable to use one stage of the ordinary audio-frequency amplification followed by one stage of push-pull amplification. On the other hand, if telephone receivers, only, are to be used, one stage of ordinary amplification will suffice. The audio-frequency amplifier may be of any one of the types described in this Section or a modification of any one or more.

REFLEX SETS

PRINCIPLE OF OPERATION

31. A *reflex set* is one in which the signal is sent back, or reflexed, through part of the circuit a second time. As generally constructed, the reflex set comprises one or more stages of radio-frequency amplification, a crystal or vacuum-tube detector, and then audio-frequency amplification through all or part of the radio-frequency tubes. This system is conservative of tubes, which are a large item of expense with most types of radio receivers. Reflex sets ordinarily require a relatively large number of transformers and condensers, but these are essential to the proper functioning of the receiver unit.

For convenience and simplicity as well as economy, it is quite customary to use a crystal detector to rectify the radio-frequency signals. This eliminates the use of one tube for this purpose, although a two- or a three-element tube should give even better results. Reflexing through one tube is possible, for, so far as the tube is concerned, it is normally not operated at anywhere near its energy-output capacity. Sending the signal through the tube twice does not injure nor overload the tube. In fact, it could stand more reflexing if a suitable circuit could be devised. As it is, two- and three-tube reflex sets are also made with very little distortion introduced by the circuit or the tubes.

FUNCTION OF CRYSTAL

32. As has been intimated, the crystal detector is used to rectify the radio-frequency signals after they are amplified by one or more stages of radio-frequency amplification. The crystal detector is operated by its feature of passing currents much more readily in one direction than in the opposite direction, and does this without distortion. After rectification, the signal is sent back through the same tubes for further amplification at audio frequency.

Considerable difficulty is experienced in practice in securing crystal-detector material that will retain a sensitive condition for long periods of time. This difficulty is somewhat aggravated by the fact that rather strong currents are sent through the crystals, and such strong currents are hard on most types of crystal material. Very frequently, reflex sets have been put into use with fair results, which have been greatly increased by the substitution of a better type of crystal. A two-element electron tube will function with practically as little distortion as will a crystal detector, so long as it is operated properly and not overloaded. A three-element tube will also serve as a pure rectifier with the grid and plate elements connected together as the second element or with all three elements connected separately so long as excessive regeneration is not present.

ONE-TUBE REFLEX SET

33. One of the most popular reflex sets is the type that uses one three-element tube with the necessary auxiliary apparatus. This type of set is very economical to operate, especially when the tube requires only a dry cell for the filament. With a good antenna, such a set should give head-phone reception over a very large-distance radius, and more or less satisfactory loud-speaker reception on very close stations. With head telephones, which are recommended, it is possible to secure a very good quality of reception with all the volume that is necessary for local stations and even for those that are at some distance.

Single-tube reflex sets are made with some variations in connections. Sometimes the changes look greater in the way the circuit diagrams are drawn than they do when the diagrams are redrawn in the more conventional manner. A typical wiring diagram for a one-tube set is shown in Fig. 10. The inductance of the main tuning coil *a* may be varied by providing suitable taps for securing wave-length adjustments, or a large variometer may be used for this purpose. The variable con-

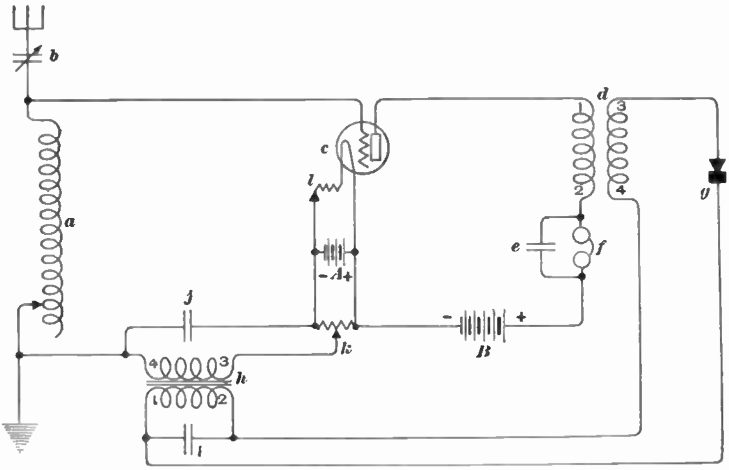


FIG. 10

denser *b* assists in tuning the antenna circuit and should have a capacity of .0005 microfarad. A vernier attachment will be of value in tuning the set, particularly to weak signals.

34. The signal that is tuned in is impressed on the grid element of the tube *c*, Fig. 10. This tube amplifies the signal at radio-frequency and sends this strengthened signal through the radio-frequency transformer *d*. These currents pass at radio frequency through the primary of this transformer and then through the shunt condenser *e* around the telephone receivers *f*, which carry the normal plate current but will not allow the high-frequency fluctuations to pass through them. The secondary winding of the radio-frequency transformer now receives the radio-frequency signal and sends it through the crystal detector *g*. This detector acts in the usual manner to rectify the signal to audio frequency. This circuit also includes the primary winding of an audio-frequency transformer *h*. In order that the radio-frequency currents may pass properly through the circuit it is necessary to use a .002 microfarad fixed condenser as shown at *i* connected across the primary winding of the audio-frequency transformer.

The audio-frequency signal is then impressed by means of the secondary winding of the transformer *h* on the grid of the tube *c*. The current must pass through coil *a* in reaching the grid, but the opposition to, or effect of this coil on, audio-frequency currents is practically negligible. However, the radio-frequency currents to which coil *a* is tuned cannot pass through the secondary winding of the transformer *h*, and it is necessary to provide the shunt condenser *j* of approximately .001-microfarad capacity. This condenser completes the path for radio-frequency currents to reach the negative filament terminal of the grid circuit. The proper grid bias is obtained by connecting the grid return to the slider of a potentiometer *k* shown connected across the *A* battery. The set should be operated with this slider as near the negative end of the potentiometer as possible without undue extraneous noises. The potentiometer should have a resistance of 400 ohms, and some means should be provided for disconnecting one end from the *A* battery when the set is not in operation.

35. The signal next passes through the tube at audio frequency in the usual manner. The amplified currents can readily pass through the primary winding of the radio-frequency transformer *d*, Fig. 10. Since this transformer is not adapted to the transfer of energy at audio frequency from the primary to the secondary, little loss will occur from this source. The audio-frequency energy therefore passes through the telephone receivers *f*. Some small amount of audio-frequency energy may pass around the telephone receivers through the shunt condenser *e*, but it is not important enough to consider. The plate-voltage supply is from the *B* battery through the telephone receivers and primary winding of the radio-frequency transformer.

The type of tube to use will depend largely upon personal preference. Any of the dry-cell tubes will give good service in a reflex set besides possessing the feature of economy in operation. The size and type of *A* battery must be suitable for the particular tube that is selected. A plate voltage of say 40 to 60 volts will suffice for good signal output. Dry-cell *B* batteries are to be recommended especially when only one tube is operated therefrom. A filament rheostat is provided at *l* by which the filament current may be controlled.

36. Any good types of radio- and audio-frequency transformers should give good results so far as these devices are concerned. The connection scheme to follow is to connect the transformers, Fig. 10, as nearly as possible in the usual fashion. The terminal on transformer *d* that is marked *1* is the one that goes to the plate, and *2* connects with the *B*+ terminal, through the telephone receivers, as in any other amplifier circuit. Terminal *3* is the one that would go to the grid, and *4* to the filament, or *A* battery of the next stage. A recommended connection for the terminals of transformer *h* follows: Terminal *1* in the figure is the terminal that would connect with the plate, and terminal *2* with the *B*+ terminal, in a regular amplifier circuit. In a like manner, terminal *3* would connect with the grid, and *4* with the negative *A* battery of the succeeding tube. It seems that this transformer works better in some cases with the two secondary terminals reversed, and this connection should be tried. It would also be well to interchange the two primary terminal connections and note whether any improvement is secured thereby.

37. The incoming signal is handled in the manner summarized in the following sequence of events:

The antenna circuit is tuned to the desired signal by the antenna coil *a* and condenser *b*, Fig. 10. The signals, at radio frequency, oscillate in the local circuit comprising the coupling coil *a*, condenser *j*, and the grid-to-filament portion of the tube *c*. Here the signal is amplified, still at radio frequency, and fed into the plate circuit where the signal passes through the primary of transformer *d*, condenser *e*, the *B* battery, and the plate-to-filament portion of the tube *c*. The signal is next transferred to the local circuit through the secondary of the transformer *d*, crystal detector *g*, and condenser *i*.

The rectified signal then passes from this circuit through the primary winding of transformer *h* at audio frequency. The signal is next transferred to the secondary winding of transformer *h* where it passes through the local circuit, which also includes coil *a*, the grid-to-filament portion of tube *c*, and whatever portion of potentiometer *k* that may be included between the negative filament terminal and the slider. After amplification at audio frequency, the current passes through the circuit composed of the primary winding of transformer *d*, telephone receivers *f*, the *B* battery, and the plate-to-filament elements of the tube *c*.

38. There are several variations of the single-tube reflex set, many possessing features that are desirable. It is well to make preliminary tests of the set before incorporating these features in the circuit as a permanent feature, as often such modifications do not produce the results expected. As has been mentioned, a variometer could be substituted for the tapped coupling or tuning coil. Also, it is frequently desirable to connect a variocoupler as the tuning element. The primary of the variocoupler would then form the antenna tuning device, either without, or preferably with, a variable series condenser. The rotor of the variocoupler would be connected as the secondary to feed the energy to the grid of the tube. This secondary coil is normally tuned by a shunt variable condenser of a size great enough to tune the coil over the desired wavelength range. The addition of this variocoupler does not affect the operation of the remainder of the set, but does improve the selectivity to a very great extent.

39. Instead of the variable condenser *b*, Fig. 10, in the antenna lead, it is possible to use two or three or even more fixed condensers, with various capacities such that the wavelength range may be approximately covered as different ones are used. Good results may sometimes be obtained without any antenna condenser. The audio-frequency transformer with its condensers *i* and *j* may be omitted from the circuit with probably some loss of signal strength. A small capacity condenser is then placed in the grid circuit and the two leads from the detector circuit are connected across it. A variable condenser connected across the primary or secondary windings of the radio-frequency transformer may help to tune the transformer to the desired signal as an aid to securing selectivity. This feature of tuning is applicable only to certain types of transformers, and is generally not feasible.

40. Many attempts have been made to add regeneration to a reflex set. For example, regeneration is often introduced by a plate-circuit variometer, or by a coil in the plate circuit that feeds energy directly to the grid circuit. Such devices are not feasible in reflex sets, as their use does not increase the signal strength beyond that obtainable by the regular reflex action. The limit of any regenerative action is reached when the feed-back of energy into the grid circuit is so great as to cause the set to oscillate. This condition is, or should be, obtainable in a reflex set, without the necessity of other apparatus. In fact, with some reflex sets it is necessary to maintain a positive bias on the grid by means of a potentiometer to prevent the tube from oscillating.

41. Some general information as to the method to pursue in tuning the set should be of value. If possible, set the crystal detector on a sensitive point, or better still, use a fixed crystal; that is, one that retains a sensitive condition permanently. If there is a coupling device, such as a variocoupler, this should be adjusted with fairly close coupling between the windings for maximum signal strength. Adjust the filament rheostat so that the filament of the tube is operated at its rated voltage.

Vary the adjustable tuning devices, either simultaneously, if not too numerous, or by setting one or two at various positions and move the other tuning device, or devices, over their range of wave-length adjustments. It is important that the tuning be not carried on so fast as to skip over any station. The main tuning element should be reset to another wave-length and the tuning condenser or other auxiliary device again varied over the full range of possible adjustments. In case there is a potentiometer, it should be adjusted so that its pointer is near the negative filament end to make the set most sensitive while tuning for signals.

Various setting combinations should be tried until one is found that brings in signals. The signals may then be cleared up by readjusting the tuning devices to the wave-length of the desired station. This should be done carefully, as much of the success of operation depends on the closeness of the tuning. It is a fact that very often a reflex set will function, and it will later be found that the crystal detector is out of adjustment. This, naturally, does not apply to fixed crystals, but it should be remembered that some types of these are more sensitive than others. If the signal strength will permit, it is very desirable to decrease the temperature of the filament of the tube. This is accomplished by increasing the resistance of the filament rheostat and should be done whenever possible.

TWO-TUBE REFLEX SET

42. The two-tube reflex sets are made in several different styles just as are the one-tube sets. The two-tube set nearly always has two stages of radio-frequency amplification, detector action by a crystal, and either one or two stages of audio-frequency amplification reflexed through the two tubes just mentioned. Occasionally a two-tube reflex set has one radio-frequency stage, a crystal detector, an audio frequency reflected through the radio-frequency tube, and another tube added to give regular audio-frequency amplification. Less often, a set with a second tube to perform merely the rectifier action, possibly with some regeneration, is known as a two-tube reflex set.

43. The two-tube set described in the following text employs two stages of radio-frequency amplification, detection with a crystal detector, and one stage of audio frequency ampli-

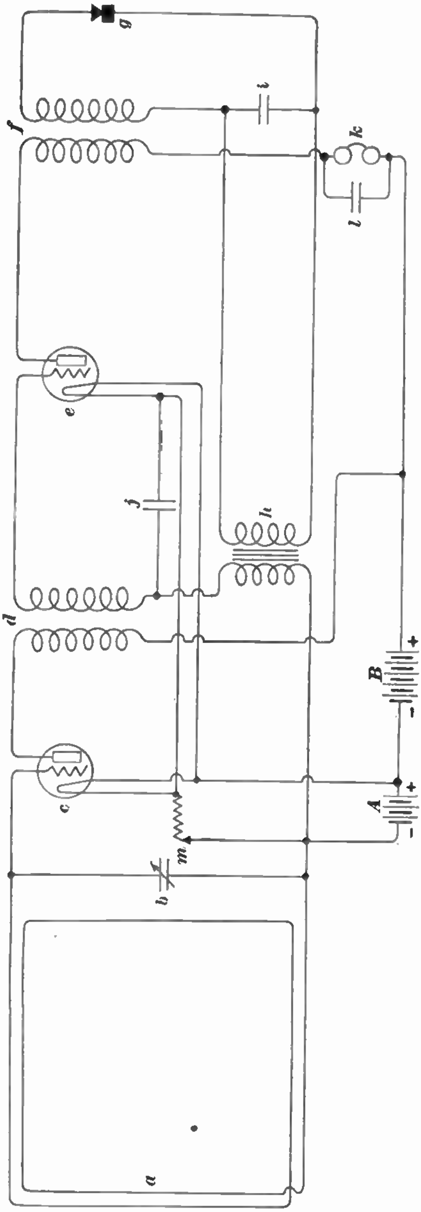


Fig. 11

cation by the second radio-frequency tube. The wiring diagram of this set is shown in Fig. 11. The set is illustrated as connected with a coil or loop antenna *a*, which is tuned by the .0005-microfarad variable condenser *b*. Reception should be possible over considerable distances with a good coil antenna, but can generally be much improved by a larger antenna. In this event, the coil antenna would be replaced by the secondary coil of a variocoupler, the primary winding of which would be connected directly in the antenna - to - ground circuit. From the tuned circuit, the signal is impressed on the grid of tube *c*, which amplifies the signal at radio frequency. The signal next passes through the radio - frequency transformer *d*, which in turn delivers the signal to the grid of tube *e*. After further amplification at radio frequency, the signal is sent through another transformer *f*. The radio-frequency signal is now rectified by the crystal detector *g*, from which it passes to the primary winding of the audio-frequency transformer *h*. The rectifier action and resultant signal is much improved by a .002-microfarad fixed condenser *i*. The secondary winding of transformer *h* forms part of the grid circuit of tube *e*. Therefore, the audio-frequency signals received by the secondary winding of transformer *h*, from the primary, will be impressed on the grid of tube *e*.

This action can take place through the secondary of transformer *d* without any bad results, since this type of transformer does not have much effect on audio-frequency currents. However, radio-frequency currents cannot pass through the secondary winding of transformer *h*, so it is necessary to shunt it with a small fixed by-pass condenser *j* of .001- to .002-microfarad capacity.

44. To return to the signal, the tube *e*, Fig. 11, next amplifies the signal at audio frequency. The signal then passes through the primary winding of the transformer *f*, which does not appreciably affect audio-frequency currents, and actuates the telephone receivers *k*. The audio-frequency currents are now able to transfer their electrical energy into audible sounds by means of the telephone receivers. The plate voltage from the *B* battery is applied through the receivers *k*, and the primary winding of transformer *f*. The radio-frequency currents would be stifled by the telephone receivers *k*, so they must be shunted by a condenser *l*. This by-pass condenser may have a fixed capacity of .001 or .002 microfarad, or even larger.

45. The *A* battery, Fig. 11, should be of a type suitable to supply the filament energy for the tubes that are selected. For convenience and economy, the filament current of both tubes may be controlled by a single rheostat at *m*. If desired, separate rheostats may be used on the two tubes. It may be necessary to use a potentiometer across the *A* battery with the slider connected to the grid-return circuits from the two tubes. This would correct any tendency to oscillate, by the application of a positive grid bias to the amplifier tubes. As has been mentioned, such a bias may correct the tendency to oscillate, but causes a larger current drain on the *B* battery, so should not be used except when necessary. The potentiometer should have a resistance of about 400 ohms, and should be equipped with a device to open its circuit so that it will not take current from the *A* battery while the set is out of operation.

The only tuning control on this set is the variable condenser *b*, which should be equipped with some type of vernier control. Some types of transformers seem to work best in the intermediate position, that is at *d*, with a variable tuning condenser connected across the secondary winding. Since this tends to complicate the tuning, it should not be used unless it is a necessary feature in securing selectivity. The filament-current control rheostat is another device that must be adjusted, but with a good *A* battery this should need attention only rarely. The crystal detector is the only other piece of apparatus that will need attention, and then not if it is of the fixed type. There seems to be considerable variation in real usefulness between various types of adjustable and fixed crystals, so it is well to try at least two or three different ones.

46. The storage-battery types, or other larger-powered tubes, will generally give stronger signals than the smaller dry-cell types. However, the latter are convenient and economical and give results that are very good. The final output signal should be able to operate a set of telephone receivers on fairly distant stations. The set may operate a loud speaker if properly adjusted and quite close to a large transmitting or broadcasting station. However, with the addition of a fair-sized antenna and the consequent introduction of a variocoupler for tuning and coupling, the signal strength should be increased many fold.

47. Little need be said about the operating instructions for this two-tube reflex set. With the tubes operating at the proper temperature, and the crystal detector adjusted, the only tuning element is the variable condenser in shunt with the loop. This should not be rotated so fast as to pass over any signals unknowingly. After signals are brought in, the vernier adjustment on the condenser should be used to tune the set more accurately. If the crystal detector is of the adjustable type it is generally advisable to make sure that it is set on a sensitive spot.

If the set fails to function when assembled, the fault in many cases results from improperly connecting the apparatus, or from connections that are loose. The apparatus, especially the tubes and the batteries, is sometimes defective, but can generally be checked up or tried out individually. In service, the periodic recharge or replacement of batteries and the renewal of tubes are the main features that require attention.

THREE-TUBE REFLEX SET

48. As has been mentioned, the two- or three-tube reflex sets are made in various circuit connections and with different tube combinations. In the three-tube sets several different arrangements are possible. The signal is universally amplified at radio frequency by two or three stages, rectified by crystal or the third tube, and amplified at audio frequency by one or two of the radio-frequency tubes. Such a set is apt to be harder to tune than some others, but should give better results when properly balanced and adjusted.

A three-tube reflex set is shown in Fig. 12. The antenna is tuned by taps on the coil *a* and the variable condenser *b*. The secondary coil *c* of the variocoupler is tuned to the desired signal by the shunt variable condenser *d*. The incoming signal is impressed on the grid of the tube *e*, which amplifies it at radio-frequency. The signal next passes through a radio-frequency transformer *f*, which steps up the voltage and applies the signal to the grid of the next tube *g*. This tube likewise amplifies the signal at radio frequency and sends it through the radio-frequency transformer *h*. The signal next passes through the grid condenser and grid leak to the detector tube *i*, where it is rectified in the usual manner.

49. The signal, now chiefly at audio frequency, is supplied to the primary of the audio-frequency transformer *j*,

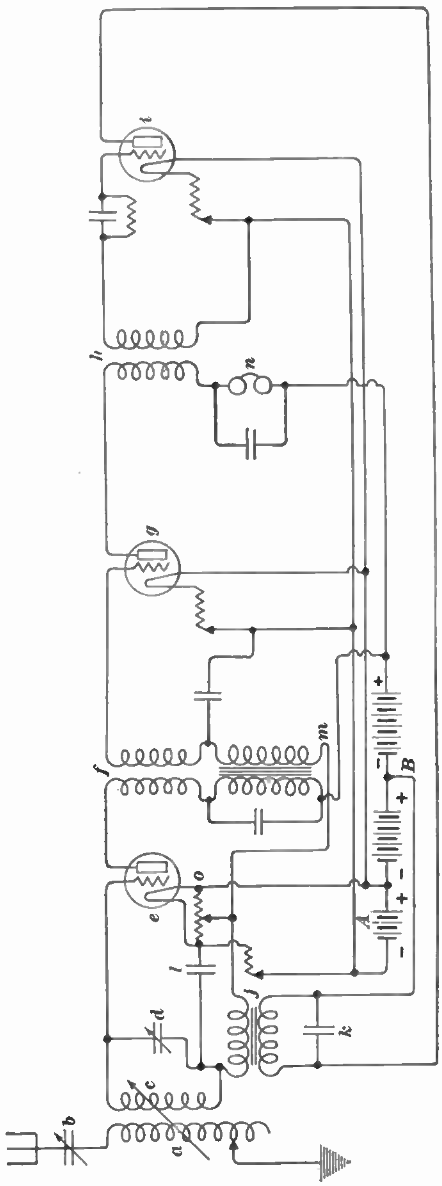


Fig. 12

Fig. 12. A .001- or .002-microfarad by-pass condenser *k* will help the operation of the set by its action on both the audio- and radio-frequency currents in the plate circuit of the detector tube. A similar condenser *l* provides a return path in the grid circuit of the tube *e* for the radio-frequency currents that cannot pass through the secondary of the transformer *j*.

This secondary winding of the transformer *j* sends the audio-frequency signal through the coil *c*, with no effect thereon. to the grid of the tube *e*. Here the signal is amplified at audio frequency and sent through the plate circuit of that tube. In that circuit it encounters the audio-frequency transformer *m* which transfers the signal from its primary winding to the secondary and then impresses it on the grid of the tube *g*. It is well to note that the audio-frequency signals are not appreciably affected as they pass through the transformer *f*, but the transformer *m* will not permit radio-frequency currents to pass. It is, therefore, necessary to connect fixed by-pass condensers around the primary and secondary windings of the transformer *m*. They may each have capacities close to .001 or .002 microfarad.

The tube *g* further amplifies the signal at audio frequency. The audio-frequency signal does not affect the transformer *h*, but does act to produce audible signals in the head telephones *n*, or loud speaker. If necessary, a .001- or .002-microfarad condenser acts as a by-pass path for radio-frequency currents that cannot pass through the windings of the telephone receivers.

50. Three individual rheostats control the filament currents taken by each of the three tubes *e*, *g*, and *i*, Fig. 12. The slider of a potentiometer *o* connects with the grid-return circuits from both the amplifier tubes. This potentiometer is used to apply as much positive bias to the grids as is necessary to prevent the set from oscillating. However, for best results this bias should be left as near the negative values as is consistent with good operation. The potentiometer is shown so connected that when the filament circuit of the first tube *e* is opened by the rheostat, the potentiometer is automatically disconnected from the *A*-battery circuit. It thus does not take current while the set is out of operation.

51. Any reliable tubes should work well in this type of set. Such reflex sets are sometimes capable of giving results nearly equal to what could be secured by a five-tube set. That is, a reflex set should, if properly assembled and adjusted, give results comparable with those obtainable by a two-stage radio-frequency amplifier, a detector, and two other stages of amplification at audio frequency. This is seldom attainable in practice, owing largely, it seems, to the losses introduced into the circuits by the extra number of devices, especially transformers. The results generally show a decided improvement over what can be obtained by a set with an equal number of tubes in which the energy is not reflexed for extra amplification. The component parts should not be mounted too closely together as is the tendency in many portable sets.

52. The *A* battery, Fig. 12, may be of any type suitable for operation with the particular tubes that are used. Small-sized *B* batteries may be desirable in portable sets, but are not recommended for general purposes on account of their relatively short life. It is very desirable to have a voltmeter available for setting the filaments of the tubes to the recommended operating voltage. If of a suitable scale range, the voltmeter may be connected across the *B* battery to check the plate voltage from time to time.

53. The set is made most sensitive, for preliminary tuning, by moving the slider of the potentiometer *o*, Fig. 12, toward the negative end until there is a strong tendency to oscillate. This is practically the same thing as regeneration, and, since it is already present, there is no need for a variometer or other means for producing regeneration in the detector tube. This detector tube, however, does not require a high plate voltage, so a special lead is taken from the first section of the *B* battery to apply about 22 or 44 volts to the plate of the detector tube *i*. As an additional preventive to oscillation, or to correct a persistent tendency to oscillate, a rather high variable resistance may be connected in the plate lead of the tube *c*. This may conveniently take the form of a 400-ohm potentiometer with connections made with one end and the slider, and with the other end not connected. It should preferably be connected between the radio- and audio-frequency transformers *f* and *m* or between the radio-frequency transformer *h* and the telephone receivers *n*.

54. The preliminary tuning is accomplished by the main antenna coil *a*, Fig. 12, and the tuning condenser *d* in the input circuit. After a station is heard, readjustments may be made to improve the reception. It is well to remember that greater selectivity can be secured by loose coupling between the primary and secondary of the variocoupler than with close coupling. If the signal strength will permit, it is advisable to reduce the filament temperature as much as possible, consistent with satisfactory operation. The potentiometer will also probably need some readjustment after the set is tuned.

In case of trouble it is always advisable to check carefully all the connections in the set. A certain amount of adjustment is often a help in securing best results from a reflex set. This is especially true because of the various effects between the several transformers that may have some coupling with each other. These effects are often manifested as a strong tendency to oscillate, which can be remedied by a rearrangement of apparatus. Some of the by-pass condensers that are shown can often be eliminated with no ill effects. This is particularly true if there is a considerable capacity effect between parts of the wiring, or in some of the apparatus. The secondary windings of audio-frequency transformers generally possess enough distributed capacity so that the shunt condensers connected to the secondary coils are not necessary.

INVERSE REFLEX SETS

55. General Principles.—The usual reflex set is capable of delivering a considerable amount of power through the audio-frequency amplifier tubes. The usual connection sends the strongest audio-frequency signals through the same tubes that handle the strongest radio-frequency signals. This signal combination is apt to overload one tube in the set while one or more may have only a relatively small amount of energy to handle. With some types of tubes, such in general as the dry-cell types, the overloading may be important, but it should hardly affect those tubes capable of handling more power.

An inverse reflex set amplifies the signal at radio frequency through the tubes in the usual order, and amplifies it through the tubes in a reverse order at audio frequency after detection. That is, in a two-tube set, for example, the signal is amplified by the two tubes at radio frequency in the usual sequence. After detection the audio-frequency signal is amplified by the second radio-frequency tube, and is then sent through the first radio-frequency tube for still further amplification at audio frequency. In this manner the tube that carries the stronger radio-frequency signal carries the weaker audio-frequency current, and the tube that amplifies the weaker radio-frequency signal handles the larger amount of audio-frequency energy.

The coupling effects are not so bad in properly assembled inverse reflex sets as they are in other types. This is especially true of the radio-frequency currents that pass on through the detector crystal or tube. In an inverse reflex set some of these unrectified currents are fed into the tube first ahead of the detector, while in the other reflex sets these currents are fed into the set at the first or second tube. In the latter case, these stray radio-frequency currents are amplified by two or three tubes as against one, or possibly two, in some types of inverse reflex sets. These currents are likely to set up various sorts of oscillations, so any method of minimizing them is desirable. Naturally, this principle does not affect or apply to the single-tube reflex sets.

56. Two-Tube Inverse Reflex Set.—The complete wiring diagram for a two-tube inverse reflex set is given in Fig. 13. The antenna circuit is tuned by the tapped coil *a* and the series variable condenser *b*. The coil *a* might be the primary winding of a variocoupler with the rotor coil *c* adjustable for coupling. The rotor, or secondary, coil *c* is tuned by the shunt variable condenser *d*. An antenna is recommended for use with this set, although good results should be possible with a loop, or coil, antenna connected in place of the secondary coil *c*. The variocoupler and condenser *b* would be eliminated in this event.

The radio-frequency signal is impressed on the grid of the tube *e*, which amplifies the signal just at it is received. The signal then progresses through the radio-frequency transformer *f* and is further amplified by the tube *g*. The radio-frequency transformer *h* next receives and then sends the signals through the crystal detector *i*. The rectified audio-frequency signal is then sent through the primary winding of the audio-frequency transformer *j*. A shunt condenser *k* helps

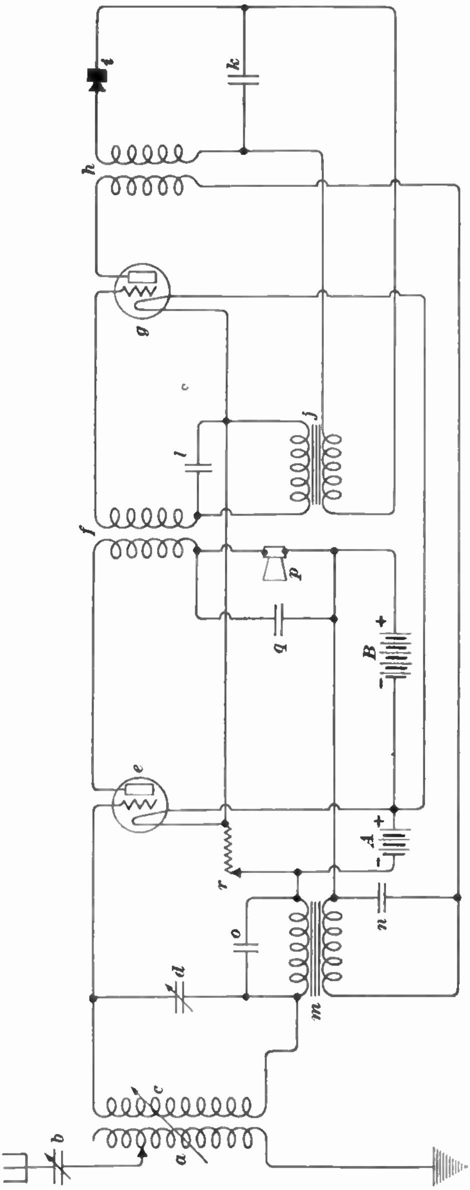


Fig. 13

handle the radio- and audio-frequency currents in this local detector circuit.

57. From the primary, the signal is transferred to the secondary winding of the audio-frequency transformer *j*, Fig. 13, which in turn impresses the signal on the grid of the tube *g*. The secondary of the transformer *j* is shunted by a small by-pass condenser *l* to provide a continuous path for radio-frequency currents in the grid circuit. The audio-frequency currents pass from the plate of the tube *g*, through the primary winding of the transformer *h* with no effect, and also through the primary of transformer *m*. The radio-frequency currents that pass through the transformer *h* cannot be established through the rest of the plate circuit, so it is necessary to connect a condenser *n* to act as a by-pass for the radio-frequency currents around the transformer *m*.

The audio-frequency signal is next transferred to the secondary winding of the transformer *m*, which in turn impresses the signal on the grid of the tube *e*. Owing to the choking effect of the secondary winding of transformer *m* to radio-frequency currents, it is necessary to use a small fixed condenser across this winding as a by-pass for such received signal currents. The audio-frequency signal is amplified by the tube *e* at the same time that it amplifies the received signal at radio frequency. In the plate circuit of the tube *e* the audio-frequency energy passes through the primary of the transformer *f*, and serves to actuate the telephone receivers or loud speaker *p*. The by-pass condenser *q* provides a path around the loud speaker *p* for the establishment of radio-frequency currents throughout the plate circuit of the tube *e*.

58. A rheostat *r*, Fig. 13, serves to control the filament current of both tubes. The set and tubes might work better if there were individual rheostats to control the filament currents taken by the two tubes. As shown in the figure, the grid return of both tubes connects with the negative filament lead. This is the desirable connection if the set can be made to work this way. If there is a persistent tendency to oscillate, it may be corrected by connecting the grid-return leads to the slider of a potentiometer across the *A* battery. The *A* and *B* batteries should be suitable to operate the tubes and set with reasonable service. Too high a plate voltage is not recommended, as such is likely to reduce the life of the tubes, especially when little or no grid bias is used.

59. The set is tuned with fairly close coupling between the coils *a* and *c*, Fig. 13. The crystal detector should be located on a sensitive spot, if possible, by listening to a strong local station while adjustments are made. A convenient way to set the crystal in other sets as well as this one, is by the signal from a small high-frequency buzzer. One single lead from the buzzer circuit will carry enough energy to the set to enable one to pick out a sensitive spot on the crystal. As soon as a satisfactory spot is found, the buzzer is disconnected and the tuning continued.

Taps on the coil *a* may conveniently be changed for approximate tuning of the antenna circuit. The condenser at *d* is for tuning the secondary coil *c*, and this condenser *d* should have a vernier adjustment for fine tuning. The condenser *b* is connected in series with coil *a* in the antenna circuit if a long antenna is used. If coil *a* does not tune to long enough wavelengths, it is convenient to connect the condenser *b* in parallel with, or across, the coil *a*. Very good results may sometimes be obtained without the antenna condenser.

For final tuning the coupling between the coils *a* and *c* should be reduced, which will materially increase the selectivity of the set. The condensers *b* and *d* may then need some readjustment to the desired signal. It may be possible to find a more sensitive spot on the crystal by readjustment. The tube life will be extended if the filament temperature can be decreased without diminishing the signal too much.

60. Four-Tube Inverse Reflex Set.—The basic principle of an inverse reflex set was illustrated by the two-tube set. A regular three-tube set is likely to be quite complicated, and very hard to assemble. The reactions and feed-back effects between parts of the circuit may be serious and difficult to control. Once assembled, such a set is capable of giving exceptional results with few adjustments and a minimum number of tubes.

A better combination seems to be one with the audio-frequency signal reflexed through two stages with a separate tube used as an audio-frequency amplifier only. A three-element tube used as a detector is also a feature of the modified inverse reflex set shown in Fig. 14. The antenna is tuned in the usual manner by a tapped coil *a* and a series variable condenser *b*. There is variable coupling between the coils *a* and *c*. The coil *c* is tuned to the desired signal by the variable condenser *d*.

The incoming signal is amplified by the tube *e* at radio frequency, just as received. The signal then passes through the radio-frequency transformer *f* and to the grid of tube *g*, which further amplifies it at radio frequency. The signal next passes

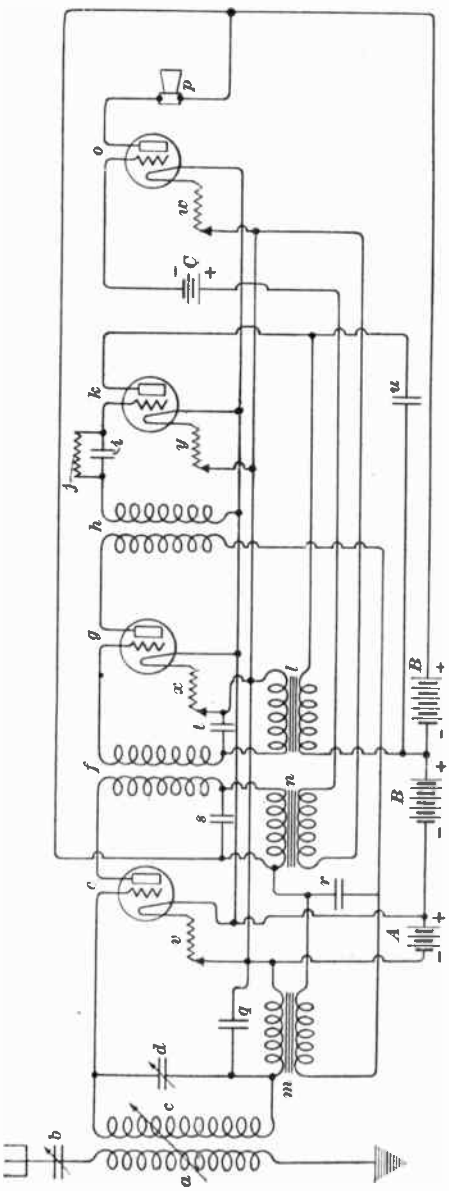


Fig. 14

through the radio-frequency transformer *h*, then the grid condenser *i* and grid leak *j*, and the tube *k*, which converts the signal to audio frequency.

61. The signal now passes through the audio-frequency transformer *l*, Fig. 14, which impresses it on the grid of the tube *g*. After amplification at audio frequency, the signal is sent through another audio-frequency transformer *m*, which transfers the signal to the grid of tube *e*. This tube likewise amplifies the audio-frequency as well as the radio-frequency received signal. The audio-frequency signal passes through the primary of the transformer *f* with no effect. When this signal reaches the audio-frequency transformer *n* it is readily transferred from the primary to the secondary winding. At this point the audio-frequency signal is impressed on the grid of the tube *o*, which is the only energy sent through this tube. In this manner the tube *o* amplifies the signal without interference and sends the strong current pulsations through the loud speaker at *p*, where these are reproduced as audible signals.

62. Some by-pass condensers are necessary in this set to provide paths for radio- and audio-frequency currents around devices that might otherwise choke out or at least seriously hamper the passage of such currents. Such by-pass condensers should be of good quality; for example, those with mica dielectric. The capacity should be close to .002 microfarad, although somewhat larger or smaller values may be found to operate better in some cases. Practically no gain will be secured by substituting variable condensers, as these do not tune any circuits but merely act as shunt paths for the signal currents. The condensers *q*, *r*, *s*, and *t*, Fig. 14, are mainly radio-frequency by-pass condensers; the condenser *u* handles audio-frequency currents chiefly. Sometimes long lead wires or the windings of the transformers provide a sufficient by-pass capacity without the addition of extra condensers.

63. For convenience and best control separate rheostats are shown at *v*, *w*, *x*, and *y*, Fig. 14, to control the filament current of the tubes *e*, *o*, *g*, and *k*, respectively. Common *A* and *B* batteries are used for all four of the tubes, so should be of a suitable type and capacity. A small *C* battery is connected so as to apply a negative bias to the grid of the tube *o* that acts as the last audio-frequency amplifier. The only bias applied to the amplifier tubes *e* and *g* is that provided by the voltage drop in the rheostats *v* and *x*, respectively.

64. The circuit of the inverse reflex set may be reviewed in its operation to clear up the sequence of events. The desired signal is received, at radio frequency, and amplified at radio frequency by tube *e*, Fig. 14. This signal then passes through *f* without affecting the audio-frequency transformers *n* and *l*. The signal, still at radio frequency, is amplified by the tube *g* and sent through the transformer *h* to the detector tube *k*. After rectification, the signal is sent through the audio-frequency transformer *l* and amplified by the tube *g*, which also amplifies the radio-frequency currents. The signal next passes right through the transformer *h* with no effect, to the audio-frequency transformer *m*. This transformer impresses the signal on the grid of the tube *e*, which thus amplifies a rather strong audio-frequency signal at the same time that it amplifies a relatively weak radio-frequency signal. This audio frequency signal now passes through the transformer *f* to the audio-frequency transformer *n*, which acts on the grid of the tube *o*. This tube finally amplifies the signal at audio frequency and sends it through the loud speaker *p* for audible reception.

65. As an aid to selectivity in tuning, the transformer *f*, Fig. 14, may be some suitable type of tuned radio-frequency transformer. Transformer *h* is normally a reliable type of untuned radio-frequency transformer. The audio-frequency transformers should have a fairly low turn ratio, else trouble is likely to be encountered from howling in the set. If desired, a telephone jack may be inserted in the plate circuit of the tube *e* in parallel with the primary of the transformer *n*. This will permit of connection of the loud speaker in this part of the circuit if the signal strength is ample.

A crystal detector may also be connected in place of the detector tube *k* and its auxiliary apparatus. This may result in somewhat weaker signals, but the elimination of one tube may be desirable in some cases. The set could then be called a three-tube inverse reflex set. With strong signals, reception should be possible without the extra audio-frequency tube *o* and its auxiliary apparatus.

66. The tuning of this set is practically the same as that of any other reflex receiver that has a similar tuner element. Both the antenna and input circuits are properly tuned to the desired signal. For preliminary tuning, the antenna coil and the secondary coil may be closely coupled, and the filaments of the tubes burning at the full rated voltage. After the approximate settings are determined, the coupling may be reduced and final tuning made as accurately as possible. It should be possible on all but weak stations to reduce the filament voltage without diminishing the signal strength too much.

With the electron tube detector of this set no trouble should be encountered from this part of the circuit.

It may be possible to use the primary coil *a* without a series condenser *b*, and to depend on taps on the coil *a* for adjustment of the antenna. The negative *A*-battery terminal may be grounded, which should tend toward quietness in the operation of the set. A further tendency toward inherent noises or a tendency to oscillate may be due to reaction between some of the transformers or other devices; this may be eliminated by a readjustment of the apparatus. Only first-class material and apparatus should be used in any radio set, and the assembly and wiring should be carefully done.

IMPROVING AUDIO AMPLIFIER

QUALITY OF APPARATUS

67. Much has been said, both here and elsewhere, about the quality of the apparatus that should be used in a radio set. It seems that this cannot be repeated too often, as the amount of inferior apparatus on the market shows. Only reliable dealers and manufacturers of apparatus should be patronized, as there is much in many pieces of radio apparatus that may not show up in a superficial inspection. Even perfect assembly work cannot correct the ills inherent in faulty apparatus.

Even the best apparatus may prove defective, but if made by a reliable manufacturer it is generally possible to secure a fair adjustment. The amount of energy handled in radio-receiving sets in particular is very small, and apparatus that introduces losses into the circuits should be guarded against. Much might also be said about special apparatus that is of passing interest in what might be termed freak circuits. While many of these are very interesting, a large number are merely variations of existing circuit arrangements. A few pieces of well-chosen apparatus will give a large number of possible circuit combinations, where it is desired to try them experimentally.

ASSEMBLY OF SET

68. The assembly of a radio set is also of extreme importance in determining whether or not best results will be secured. The component devices should not be located so close together that they establish detrimental coupling effects with each other. This is especially true of the wires and pieces of apparatus that carry radio-frequency currents, since capacity effects especially are much more likely to introduce detrimental coupling into the set. The layout of apparatus should be planned so as to reduce the necessity for using corrective features in the set after it is assembled.

While soldering, of itself, is a simple operation, a poor job of soldering can introduce very serious losses. Particularly is this true where an abundance of soldering flux, such as paste, has been used, and the excess has not been removed. It is essential that the soldering copper should be hot enough to facilitate a thorough job, and that any excess soldering flux should be carefully wiped off after the job is finished. Rosin is especially good as a soldering flux, as it is itself a good insulating material, so cannot form leakage paths by which the energy may escape. Tinned copper wire, either round or square, is very convenient, and makes a neat-looking job when properly handled. Spaghetti tubing is of considerable value as an insulating material for the wires. The wires should be rigid enough to retain their shape and position without depending on the insulation.

POSSIBLE REMEDIES FOR TROUBLES

69. Distortion is one of the commoner ills of audio-frequency amplifiers. Aside from poor apparatus, improper operating conditions are probably the worst offenders. This includes particularly the *B*- and *C*-battery voltages. As has been explained, with high-plate voltages, certain grid-bias voltages should be applied thereto. In this respect the recommendations of the manufacturers should be closely followed. A common trouble in a new set lies in getting the batteries improperly connected; that is, they may be interchanged or the terminals may be reversed. A 25- or a 40-watt tungsten filament lamp connected in series with the *B* battery will prevent the high voltage from burning out the filament of the vacuum tube if it should be connected with the *B* battery by mistake. A reversed *A* battery will give much weaker signals than will be the case when it is properly connected. A reversed *B* battery will not operate the set; a *C* battery that is reversed is likely to introduce a great deal of distortion into the amplifier.

70. A disagreeable tendency of a transformer or choke-coil coupled amplifier to oscillate or howl may be remedied in many cases by grounding the iron cores of the coupling units. A wire may be clamped by a screw to the iron core. and the wire in turn connected to the negative filament terminal of the *A* battery. This terminal of the *A* battery is ordinarily connected with the ground both for stability of operation and to reduce hand capacity effects. A metal shield placed between each stage of an amplifier and connected to the negative filament terminal will frequently eliminate the coupling effects between the coupling devices of the various stages. A potentiometer across the *A* battery with the grid return connected to the slider will prevent oscillations in the amplifiers, but this tends to introduce considerable distortion and loss of signal strength. A potentiometer is seldom used in an audio-frequency amplifier stage, and should not be necessary.

Some information has been given about clearing up signals with a small fixed condenser or a grid leak connected in different ways across a transformer. These condensers might also be tried in connection with the choke-coil coupled amplifier, although the aid is not apt to be so important in this latter case. A large fixed condenser of, for example, say 1 microfarad connected across the *B* battery tends to smooth out any sudden changes of current or noises in the plate circuit, and tends toward more quiet operation of the amplifier.

ELIMINATING INTERFERENCE

STATIC EFFECTS

NATURE OF STATIC

71. Of all interference, static is the form that is the hardest to eliminate in the receiving set. It takes many forms, from sharp report-like noises to a series of crackling noises following one another in rapid succession. These effects are considered to be established by electrical discharges sometimes close, and at other times many miles away. They are most serious in the summer months, but even then are quite erratic in that the static may be very serious at one time and not objectionable at another.

REDUCING STATIC INTERFERENCE

72. The large outdoor antenna brings in good strong signals, but it also collects its share of static. One of the best ways to attack the problem is to use a fairly small antenna system that will be more selective to incoming signals, and then to employ a sensitive type of receiving set, especially the tuner unit. A short antenna, say of 30 feet, either indoor or outdoor, will give good results when connected with a sensitive receiver even with considerable static. A coil or loop antenna is little affected by static and other kinds of interference, and is one of the best types to use. An extremely long antenna, known as a wave-length antenna, is not much affected by static and other disturbances. Its length should be close to the wavelength of the signal that is to be received. This antenna is so long as to render this type useful chiefly in commercial receiving stations.

Selectivity against static in the receiving set may be secured by using tuning elements that permit of tuning the set accurately to one particular wave-length. This is frequently aided materially by radio-frequency amplifiers of some types. A relatively low-resistance grid leak will also tend to reduce static effects as they are sent through the radio set.

REDUCING OTHER INTERFERENCE EFFECTS

73. Some other types of interference may be termed man-made as distinguished from static interference, which is a product of nature. Among others the more common are those from X-ray, violet-ray, and other high-frequency machines. These may best be reduced in intensity or eliminated at the source with suitable precautions, but unfortunately this is seldom done. A selective receiver is naturally troubled less from such devices than is one that is not so selective.

Induction from power lines may be remedied in many cases by locating the antenna at about right angles with the interfering source or line. Trouble from leaky insulators or faulty equipment on power or electrical supply lines is best eliminated by removing the defective apparatus. Such troubles are best located by a coil antenna mounted on a portable set, and this is used to determine the location of the interference by taking several bearings on the disturbance. High-voltage smoke precipitators and other kindred devices can cause enough disturbance to prevent the reception of signals on any wave-length in their vicinity. Such trouble should not be experienced if the various circuits are properly connected and grounded, and the auxiliary apparatus suitably shielded.

Interference from oscillating, or radiating, receiving sets is a source of interference that can best be eliminated by proper instruction to the offenders in the operation of their sets. Such interference is hard to eliminate at the receiving set, except by moving over to receive signals on another wave-length, a procedure that may not be desirable.

FADING

74. While not directly a cause of interference, the fading of signals is sometimes a disturbing element in the reception from distant stations. It is most noticeable as a more or less periodic and gradual appearance and disappearance of signals from a weak station, or, particularly a station so distant that its signals are just coming through. Increasing the power at the transmitting station seems to be about the best way to reduce the fading effect if the increase is enough to send the signals through continuously. In this connection it is well to note that some of the very short-wave signals are not affected so much by seasonal and fading effects as are the signals sent on longer wave-lengths.

Much of the consistent and really long-distance reception of signals is due to the fact that the apparatus is working to its best advantage. Some of the extreme cases are probably due to a peculiar combination of factors in nature that combine to give the unusual results secured only while these conditions obtain.

Many of the cases of long-distance reception of signals by crystal sets seem to be direct from the sending station. Other cases have appeared to be accomplished by the radiation of the signal by a local powerful receiving set.

BROADCAST RECEIVING SETS

APPARATUS AND CIRCUITS

BRIEF REVIEW OF STANDARD CIRCUITS

INTRODUCTION

1. The signal energy received at a receiving station from a distant radio transmitter is very minute. This energy must be utilized in the best possible manner to interpret or reproduce the signals originating at the distant transmitting station. The receiving set must, therefore, be fairly sensitive to respond to the weak radio signals.

The sensitiveness, or ability to respond to weak signals, would not be of very great moment if the receiving set were to respond to several signals of different frequencies at one time. The set must be able to respond best to signals of the frequency to which it is tuned and remain unresponsive to all other frequencies; in other words, the set should be selective.

Aside from its sensitiveness and selectivity, the receiving set must possess other characteristics, chief among which are faithfulness of reproduction, or absence of distortion, and ease of operation. The volume must also be large enough so that the listener can hear with comfort; this requirement can usually be met by increasing the signal strength with one or more stages of audio-frequency amplification. When in operation the receiving set should not act as a transmitter; some consideration should be paid to the reception of signals at other receiving sets. Sets utilizing the regenerative principle of operation are frequently the offenders in this regard, especially when the feed-back of energy is so great as to establish oscillations.

SINGLE-CIRCUIT TUNERS

2. A single-circuit tuner is shown in Fig. 1. This is the simplest form of practical tuning device and is used in many receiving sets. The adjustment for a given frequency or wave-length is made by means of the variable condenser *a*. The inductance coil *b* is sometimes made adjustable or at least interchangeable with a similar type of coil having the required inductance. An auxiliary condenser *c* may be used to modify

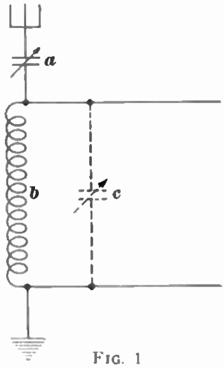


FIG. 1

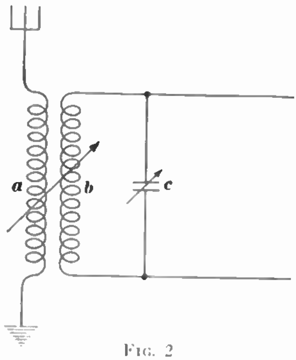


FIG. 2

the wave-length of the tuning circuit. The output of the tuner may be connected so as to operate a detector tube, or it may be introduced into the grid circuit of a radio-frequency amplifier, which will increase the amplitude of the signal at radio frequency.

As a rule, single-circuit tuners are not very selective, and for this reason, the more selective double-circuit tuner is preferable.

TWO-CIRCUIT TUNERS

3. The two-circuit tuner, shown in Fig. 2, consists of two distinct circuits coupled to each other by means of the inductance coils *a* and *b*. The coils are in separate circuits and used in conjunction with a certain amount of capacity. The antenna coil with the antenna capacity forms an open oscillating circuit. The coil *b* and the condenser *c* constitute a closed oscillating circuit. The antenna circuit may be tuned to the desired frequency, or it may be so arranged that its natural period is entirely out of tune. In this case all tuning is done in the secondary circuit. The output of the secondary circuit is used either for detecting or amplifying, at radio frequency.

ULTRA-AUDION CIRCUIT

4. The ultra-audion circuit of De Forest is one of the earliest types of regenerative circuits. It is shown schematically in Fig. 3. The coil *a* and the condenser *b* serves both as the tuning devices in the antenna circuit and also as a by-pass for the high-frequency currents in the plate circuit of the tube *c*. The coil *a* may consist of 100 turns of No. 22 B. & S. gauge double-cotton covered copper wire wound on a treated paper or bakelite tube and tapped at every tenth turn. The condenser *b* may have a maximum capacity of .0005 microfarad. The vacuum tube *c* may be either of the hard or the soft type. However, if a soft tube is used, the grid leak should be connected to the negative terminal of the *A* battery. The grid condenser *d* should have a value of .00025 microfarad and the grid leak 2 to 5 megohms.

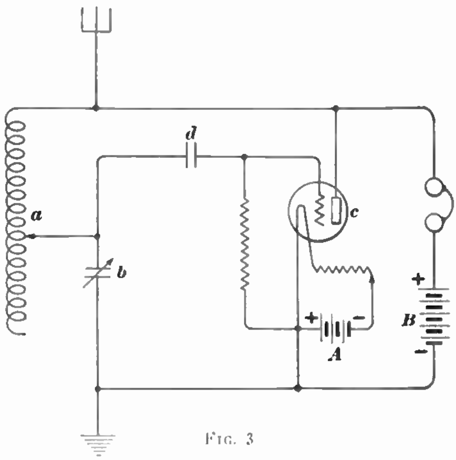


FIG. 3

The set is tuned by means of the switch arm near coil *a* and by varying the capacity of the condenser *b*. The same adjustments will also vary the degree of regeneration. It is, therefore, necessary to adjust the values of inductance and capacity that the circuit will be properly tuned, and, at the same time, that the right amount of feed-back obtains. This may best be found by trial.

REGENERATIVE SETS

5. Principles Involved.—The use of regeneration aids materially in increasing the range of a receiving set. Regeneration is based on the feed-back of energy from the plate circuit of a detector tube to the grid circuit of the same tube, where the energy is utilized to produce further amplification. Various methods are employed to obtain this result. All these methods, however, depend upon either one or both of the two fundamental principles of induction; namely, electrostatic and electromagnetic.

The electrostatic, or capacity, feed-back is usually obtained when the grid and the plate circuits are in resonance. The energy is then supplied from the plate to the grid circuit capacitively through the elements of the tube. The feed-back may be increased by connecting a small condenser across the plate and grid terminals; this, however, is very seldom required in practice.

Feed-back by electromagnetic induction is obtained by means of a coil connected in the plate circuit and coupled to another coil in the grid circuit of the tube. This arrangement has been found more reliable in operation, as the feed-back may be more easily controlled.

6. Practical Regenerative Set.—In Fig. 4 is shown a schematic diagram of connections of a regenerative set with two stages of audio-frequency amplification. A wiring diagram and an actual layout of the apparatus of the same set are shown in Figs. 5 and 6, respectively. Other layouts may be just as good or probably better. The same reference letters will be used to designate corresponding parts in each of the three figures.

The tuner consists of an untuned primary coil *a* coupled to the secondary coil *b*, which is tuned by means of the conden-

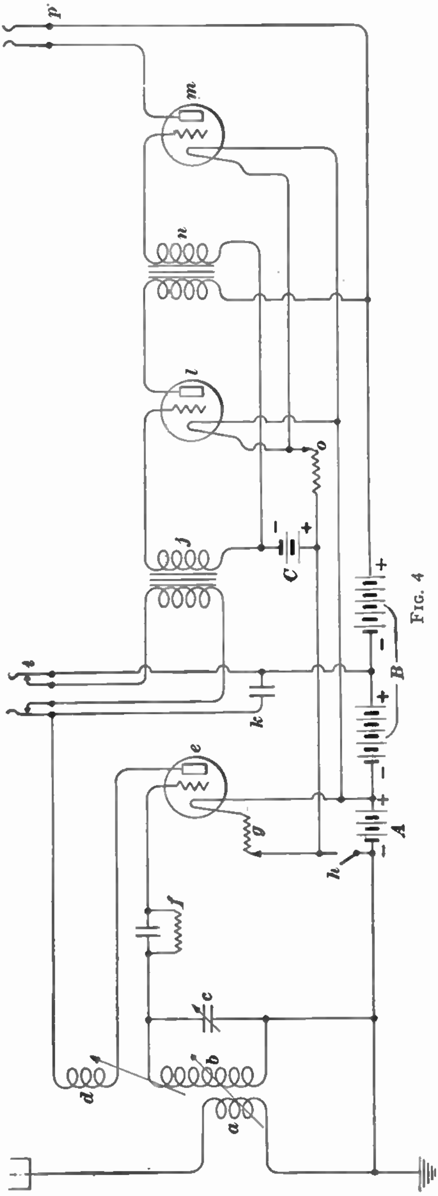


Fig. 4

I L T 450—16

ser *c*. In this case the coupling between the primary coil *a* and the secondary *b* is variable, but this condition is not always required. Very good results may be obtained with a fixed coupling. The tickler coil *d* is coupled to the secondary *b*, and the amount of feed-back may be varied by changing the position of coil *d* with reference to coil *b*.

The output of the tuner *b c* is directed to the grid circuit of the detector tube *e* through the grid condenser and leak *f*. The filament current of the detector tube is controlled by means of the rheostat *g*. A filament switch *h* is provided to open or close the *A*-battery circuit. The output of the detector may either be taken to operate a pair of telephone receivers through the jack *i*, or it may be delivered to the amplifier through the audio-frequency transformer *j*. In either case there is a .001-microfarad condenser *k* to

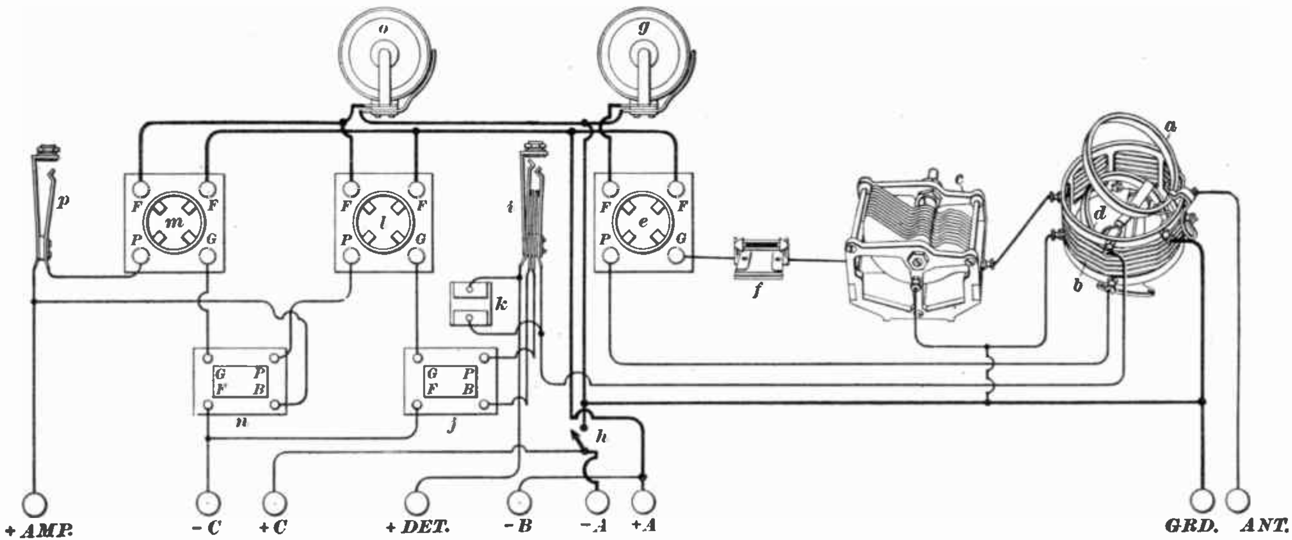


FIG. 5

act as a by-pass for the high-frequency pulsations in the plate circuit of tube *e*.

7. The energy delivered to the amplifier is first amplified by the tube *l*, Figs. 4, 5, and 6, and then by the second amplifier tube *m*, the coupling being through the transformer *n*. The filament current of both the amplifier tubes is controlled by means of the one rheostat *o*. The output of the second amplifier tube is taken through the jack *p*.

The *A*, *B*, and *C* batteries must have voltages suitable to the tubes in use. The plate-battery voltage is generally the same

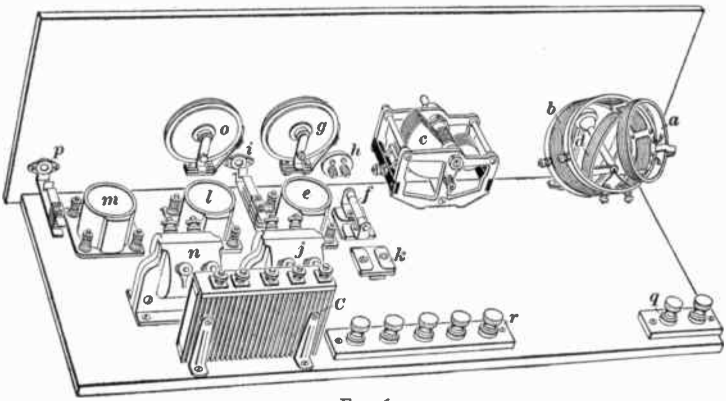


FIG. 6

for all types of tubes, except in the case of detector tubes where a lower voltage is required. The *A*, or filament, battery varies with the different types of tubes. This information is usually provided by the manufacturer of the tube. The *C*, or grid-bias, battery may have a value of 1½ to 4½ volts. In all cases the manufacturer's instructions should be followed implicitly to obtain maximum operating efficiency from the tubes.

8. The three coils *a*, *b*, and *d*, Fig. 4, may be honeycomb coils, spider-web coils, or the coils of a variocoupler. In Figs. 5 and 6, a vario-coupler is shown in which the coils *a* and *d* are movable. The antenna coil *a* consists of 15 to 20 turns of No. 22 insulated wire, bank wound. The coil is mounted on a hinged bakelite frame and may be fixed in any desired position.

The coil *b* consists of 45 to 60 turns, bank wound with 10 turns to a group and an air space between adjacent groups. This coil is tuned with the condenser *c*. With a .0005-microfarad variable condenser and a 45-turn coil, a wave-length range of from 250 to 600 meters may be obtained. The tickler coil *d* consists of about 25 turns of No. 22 insulated wire, and is mounted on a shaft so that it can be controlled by means of a dial on the front of the panel.

Two subpanels *q* and *r*, Fig. 6, are used to mount the binding posts. Panel *q* has the antenna and ground binding posts, and panel *r* has the battery binding posts. The wiring should be as direct as possible, and provision should be made that the connecting wires are not too close to each other. All connections should be soldered or at least well made by means of binding posts.

The set is tuned with the condenser *c* and the volume regulated by means of the feed-back coil *d*. Movements of coil *d* will frequently detune the set and it may be necessary to readjust the set for a given setting of the tickler coil.

SPECIAL RECEIVING SETS

SCOPE

9. There are many radio receiving sets that have some special or distinctive feature or features in the circuit arrangement. Some of these refinements tend to simplify the set, particularly its adjustment and operation. More often the advantage is one of greater selectivity and volume than is obtainable with the more conventional designs.

Many of the special sets are more or less critical in their adjustment and assembly, but operate remarkably well when once adjusted. Some of these circuits are a failure or give only mediocre success in the hands of rather inexperienced constructors. Some reveal a high type of development work in the application of both old and new principles of radio, while others are mainly trick circuit changes. These particular cir-

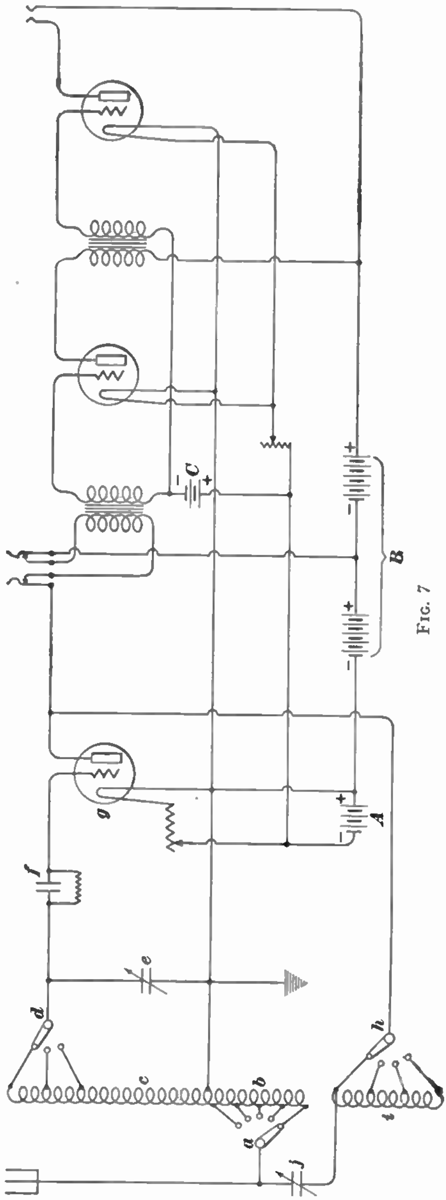


Fig. 7

cuits are grouped together more because they are all special rather than because they have essential principles in common. Only a few of the more important circuits have been included in this survey as typical of some of the developments in the field of radio.

REINARTZ SET

10. Circuit.—The Reinartz set is a special type of receiver that makes use of an unusual tuning coil. A rather small portion of the coil is used in the antenna circuit. Another portion of this same coil is employed as a coupling or supply circuit into the grid of the tube. Feed-back, or regeneration, is secured by another portion of the same coil.

A circuit diagram of the Reinartz tuner with two stages of audio-frequency amplification is shown in Fig. 7. The switch *a* connects, through taps, with the turns of coil *b*, and permits the use of the proper number of turns in coil *b*. The greater or less number of turns in coil *b* the stronger or weaker will be the coupling with coil *c*. Coil *c* is ordinarily a continuation of the winding *b*, and is wound on the same form, but is labeled here, for convenience as another coil. The antenna to ground circuit includes coil *b* only, and, since only a very few turns of wire are used, the antenna circuit is not tuned.

Coil *c* has three taps toward one end that connect with the contact switch *d*. These taps help to cover approximately the desired wave-length range. The tuning of the set is performed by means of the condenser *e*. The signal then passes through the grid condenser *f* to the detector tube *g*.

Regeneration is accomplished by a shunt connection from the plate circuit of tube *g*, Fig. 7, to the input circuit. This connection passes to the switch arm *h*, which connects with tapped contacts on the coil *i*. The approximate regeneration setting is made by the connection to one of the taps of coil *i*, and fine adjustments are secured by the variable condenser *j*. Two stages of audio-frequency amplification are added to the tuner. The construction and operation of the amplifier do not differ from those of other amplifiers.

11. Construction.—The coils *b*, *c*, and *i*, Fig. 7, may conveniently be wound on one continuous piece of tubing. They should occupy the relative positions shown in the figure. The tubing for coils *b*, *c*, and *i* should be of bakelite or other similar material, about 3 inches in outside diameter. A length of 8 inches will accommodate all the wire if it is wound in a single layer. If the coils are wound with bank-winding a length of 5 or 6 inches should suffice. Number 18 to 24 B. & S. gauge double-cotton or double-silk covered wire is very satisfactory. Any insulating compound, such as shellac, should be used very sparingly, if at all.

A tap should be made on coil *b* at every turn, the total number being ten. Coil *c*, which is really a continuation of coil *b*, has about 40 turns to the first tap, then 15 more are added by each of the other two taps for the usual broadcast range. Only 15 turns should be used on the main coil *c* with 10 turns between taps if the set is to be used for receiving signals on the higher amateur wave-lengths. A .0005-microfarad condenser at *e*, and also at *j*, should serve to cover the wave-length range. With well-designed condensers the tuning and the signal strength will be more satisfactory, than with inferior apparatus.

The grid condenser *f* should have a capacity of .00025 microfarad. In general, a good type of fixed condenser with a mica dielectric will give the best results. The grid leak should have a resistance somewhere near 2 to 5 megohms. There may be some gain by using a variable grid leak, but such is seldom advantageous in practice. Coil *i* consists of 45 turns tapped at each fifteenth turn. There should be only a short distance between the adjacent ends of coils *b* and *i*.

If more convenient, all the coils may be wound on a spider-web coil frame. This would consist of a circular wooden core about 2½ inches in diameter with 9 radial pins or spokes. The wire would be wound back and forth between the spokes, starting, say, with coil *i*. The type of *A* and *B* batteries to use will depend largely on the type of tubes. In any event the plate voltage should hardly exceed 45 volts on any detector tube. The amplifier battery may range from 65 to 90 volts. The *C* battery need not be used with a low potential *B* battery.

12. Tuning.—The tuning of the Reinartz set is somewhat different from that of most other types. The more turns of coil *b*, Fig. 7, there are connected in the circuit, the greater will be the signal strength picked up, and, to some extent, the poorer will be the selectivity. In general, it is well to use a large portion or all of coil *b* for preliminary tuning. Also, it is often more convenient to tune with a large amount of regeneration; that is, with a large part of coil *i* and condenser *j* connected in. The regeneration should not be carried so far as to cause the set to oscillate or howl while tuning is under way. As has been mentioned, the actual tuning is performed chiefly by the condenser *e*.

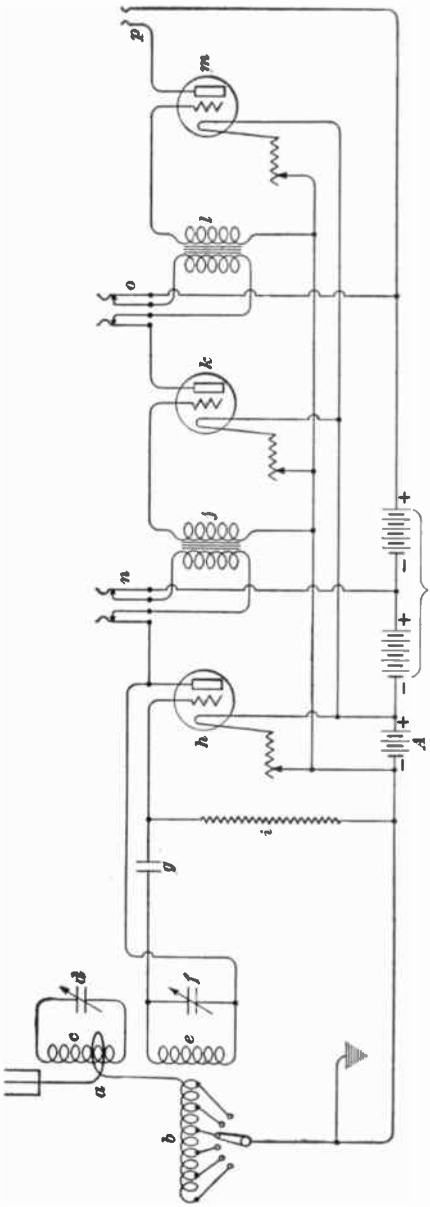


Fig. 8

When a station is once received, it is generally advisable to decrease the number of turns of coil *b*. The regeneration, or feed-back, should be adjusted so as not to introduce any distortion into the signal. It is also always well to decrease the filament current to as low a value as is possible, consistent with good reception.

FOUR-CIRCUIT TUNER

13. Circuit Diagram.—The four-circuit tuner comprises four circuits that may be tuned; namely, the antenna, or pick-up, circuit; the grid, or input, circuit; the plate, or output, circuit; and an auxiliary wave-trap circuit. A circuit diagram of this type of tuner with two stages of audio-frequency amplification. is shown in Fig. 8. The construction of the set is shown in Fig. 9.

The reference letters apply to similar devices in both figures.

The antenna, or pick-up, circuit includes the coils *a* and *b* connected in series. Coil *a* consists of a single turn wound over the coil *c*. Coil *b* is tapped and serves to tune the antenna circuit, approximately. Coil *c* and the variable condenser *d* form a closed oscillating circuit that receives its energy from coil *a* and delivers it to the grid tuning circuit consisting of the coil *e* and the condenser *f*. The antenna tuning coil *b* and the grid coil *e* are at right angles, so the induction between them is negligible. From the coil *e* and condenser *f* the energy passes

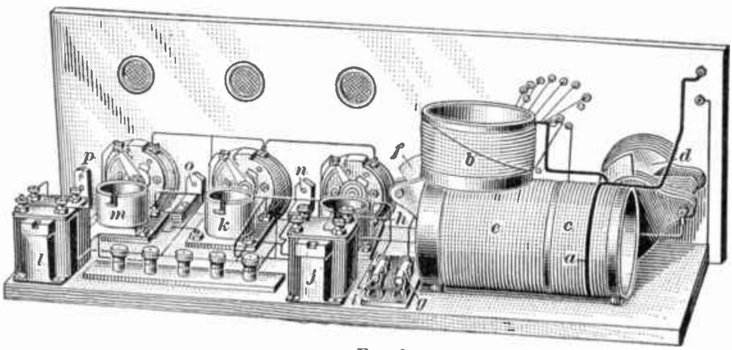


FIG. 9

through the grid condenser *g* to the grid of the detector tube *h*. A grid leak *i* is provided to perform its usual function. The feed-back from the plate to the grid is secured by a connection from the plate of tube *h* to the grid circuit consisting of coil *e* and condenser *f*.

The output of the detector tube *h* goes through the transformer *j*, the amplifier tube *k*, the second audio-frequency transformer *l* and, finally, the second amplifier tube *m*. The jacks *n*, *o*, and *p* are provided to permit of utilizing the output of any one of the tubes. Individual rheostats are used to control the filament current of the tubes. The *A* and the *B* batteries are the same as in other circuits using a detector tube and amplifier tubes. With a resistance-coupled audio-frequency amplifier a higher *B*-battery voltage must be used.

14. Coil and Condenser Data.—The coil information is given for those who may build their own four-circuit set or assemble parts that they have purchased. The main antenna coil *b*, Figs. 8 and 9, has 43 turns of No. 18 to 22 double-silk covered copper wire. This is double-bank wound on a hard-rubber tube 3¼ inches in diameter and 1⅝ inches in length. Taps are taken off this coil at the start, and at turns numbered 3, 7, 13, 21, 31, and 43. Coil *e* has 65 turns of No. 18 to 22 double-silk covered wire. This coil and coil *c* are wound on a 3¼-inch hard-rubber tube 5 9/16 inches long with only about 1/16 inch between the adjacent ends. Coil *c* has 65 turns of the double-silk covered No. 18 to 22 wire. The single-turn coil *a* may conveniently be made of tinned copper bus-wire that commonly comes in a size about 1/16 inch square.

The relative mounting positions of the coils are of extreme importance. As has been mentioned coils *c* and *e* are wound on one piece of tubing, hence their positions are fixed. Coil *b* must be mounted close to and at right angles with a side of coil *e*. The single-turn coil *a* is wound outside coil *c*, and is supported thereby.

With 65 turns of wire on each of the coils *c* and *e*, Figs. 8 and 9, the shunt condensers *d* and *f* may each have maximum capacities of .00035 microfarad to cover a wave-length from 250 to 500 meters. With fewer turns on the coils, correspondingly larger condensers should be used to cover the same range. For wave-lengths below 250 meters the inductance and capacity of both the closed oscillating circuits should be made smaller.

The grid condenser *g* may have a maximum capacity of .00025 microfarad. The grid leak *i* may have a resistance of from 2 to 9 megohms.

A fixed condenser of .005 microfarad or larger may be connected across the entire *B* battery to reduce *B*-battery noises.

The transformer *j* may have a high ratio of transformation, as high as 10 to 1. The second transformer *l* should not have a ratio higher than 5 to 1.

Rheostats should be selected to fit the tubes in use. If desired, only one rheostat need be used to control the filament current of the two amplifier tubes.

15. Tuning.—The tuning of the four-circuit tuner is quite convenient and easy, and most of it is secured by the two condensers *d* and *f*, Figs. 8 and 9. These should be equipped with vernier adjustments. An advantageous feature of this set is the fact that any station can be tuned in after it has once been located, by resetting the dials to their same positions. The antenna circuit is approximately tuned, and the volume controlled to a large extent by the various taps on coil *b*. The filament voltage should not exceed the value recommended by the manufacturer of the radio tubes. Some tuning aid may be secured by an accurate adjustment of the detector rheostat. Final tuning should be made by readjusting the verniers on the main tuning condensers until best results are secured. When properly operated, this set will be found to be very sensitive and very selective. If the condenser *d* is affected by body capacity, its rotor plates may be grounded.

FLEWELLING CIRCUIT

16. The Flewelling set represents an unusual application of the regenerative principle. When properly operated this receiver gives very good results. It may be used with a loop, or with an L- or T-type outdoor or indoor aerial. A schematic diagram of the Flewelling set is shown in Fig. 10. The coil *a* and condenser *b* serve to tune the antenna and the input circuit to the frequency of the incoming signals. The grid condenser *c* and the grid leak *d* help tube *e* to act as a detector of radio signals. The coil *f* in the plate circuit feeds energy into the coil *a*, whence it is fed through the tube again to produce stronger signals by regeneration.

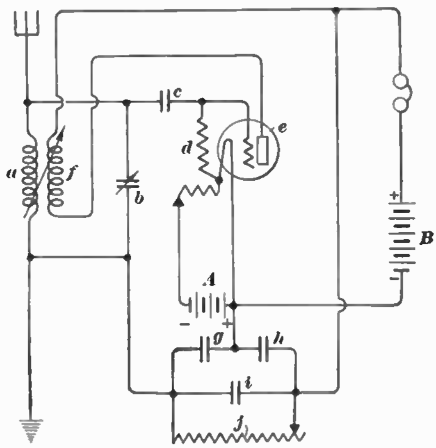


FIG. 10

The special feature of this set and one that distinguishes it from a single-circuit regenerative set is the arrangement of three fixed condensers *g*, *h*, and *i* connected as shown in the figure. The combination is used with a variable resistance *j* that is often a type of grid leak.

17. The coil *a*, Fig. 10, may be a honeycomb coil of 75 turns or any other suitable type having approximately the same inductance. Coil *f*, which is coupled with coil *a*, may also be a honeycomb coil of 50 turns. A spider-web or other suitable coil will serve equally well. The stator of a vari-coupler may take the place of coil *a*, and the rotor that of coil *f*. Condenser *b* will cover a wave-length range from 250 to 500 meters if of .0005-microfarad capacity. This condenser will tune finer if it has a vernier adjustment. A grid condenser *c* of .00025 microfarad, and a grid leak *d* of 1 to 5 megohms are the approximate values for most commercial types of tubes.

The set should work with any good make of tube of the so-called hard, or high-vacuum type. The *A* and *B* batteries will depend to some extent on the type of tube that is selected. Fairly high plate voltages may be used, but values in the neighborhood of 45 to 60 volts should prove best for general operation. The three fixed condensers *g*, *h*, and *i* should each have a capacity of .006 microfarad. These condensers, as well as the other parts of the set, should be of good material and design. Only the best grade mica condensers are suitable. The resistance *j* should be variable over a range from .1 to 1 megohm, or 100,000 to 1,000,000 ohms.

18. The Flewelling set is tuned in a fashion similar to that employed with other types of regenerative sets. Briefly, the regeneration is brought nearly to the oscillating point by increasing the coupling between coils *a* and *f*, Fig. 10. Condenser *b* is then varied until the set is tuned to the signal from a given transmitting station. The resistance *j* is then adjusted for maximum signal strength. It may also be desirable to readjust the condenser *b*, after making the other adjustments, to get the best results. It is important that regeneration should not be advanced so far as to cause the set to oscillate, as this will produce interference by radiation to neighboring sets as well as distort the signals. Only enough regeneration should be used to give a good signal strength, which should be attainable with moderately loose coupling. No advantage is secured by using variable condensers in place of the fixed condensers specified in this circuit.

SUPERREGENERATIVE CIRCUIT

19. Theory.—The Armstrong superregenerative circuit represents a refinement over the usual regenerative circuit. A regenerative circuit feeds energy from the plate circuit into the grid circuit that, in effect, tends to set up oscillations in the connected circuits. Oscillations may actually be established if the feed-back is increased sufficiently, but the reception of signals is impossible when this condition obtains. Regeneration does increase the signal strength, which reaches a maximum just before oscillations occur. Apparently the signal strength continues to increase, even after the oscillating condition is reached, but the interference or noise caused by the oscillations cannot be separated from the desired signal.

The feed-back of energy has an effect on the tube circuit similar to that found in circuits with a diminished, or lowered, resistance. As distinguished from positive or definite losses the term *negative resistance* is often applied to a circuit that increases rather than decreases the energy that passes through it.

20. The superregenerative circuit makes use of both the positive and negative resistance of the tube circuit. Special coil combinations are so arranged and proportioned that the circuit alternates periodically between the positive and negative resistance conditions at a frequency above audibility.

The *positive* or actual *resistance* condition is effective during a greater portion of the time than is the negative resistance in order to control the operation readily. The alternating-current pulsations are conveniently provided by a separate tube oscillator although it may be made to perform other duties too. The pulsations are ordinarily impressed on the grid of the input circuit.

Although an attempt is made to use inaudibly high frequencies and more or less to filter out undesirable frequencies, the superregenerative set is not entirely free from parasitic noises. This is manifest chiefly as a sort of continuous hissing sound, that may or may not be objectionable. With some individual sets it seems nearly impossible to eliminate the extra sound, but it need not be strong enough to be noticeable with signals of moderate intensity.

21. Three-Tube Superregenerative Set.—Superregenerative sets have been constructed with one, two, and more tubes with varied results. In the single-tube set, the tube acts as a detector, an amplifier, and an oscillator. A separate oscillator is provided in the two-tube set. The three-tube set possesses certain refinements that tend to improve reception. It is made in several ways, one of which is shown in Fig. 11. The coil or loop antenna connected at *a* and *b*, for broadcasting reception might be of 8 turns of wire spaced ½ inch apart on a square wooden frame 3 feet on a side. An outdoor antenna and ground can be connected at points *a* and *b*, respectively. Coil *c* should then have about 50 turns of wire, such as a honeycomb coil, to give proper results.

The tuning condenser *d* if of .0005-microfarad capacity will cover the broadcast range if the coil *c* is properly selected. A grid-bias battery *C* is used to place a negative bias of 3 to 6 volts on the detector tube *e*. A .00025-microfarad fixed condenser with a 5-megohm grid leak in parallel is somewhat simpler and should give comparable results if used in place of the negative bias. The tube *e* should be of the high-vacuum type. A potentiometer *f* is of assistance in securing proper adjustments. In practice the potentiometer is often eliminated and the grid return connected to the filament terminal that gives the better results. The tickler coil *g* should have about 75 turns. It is coupled with the input coil *c* to get the usual regeneration. In case coil *c* is omitted, for loop reception, a variometer should be used in place of coil *g*.

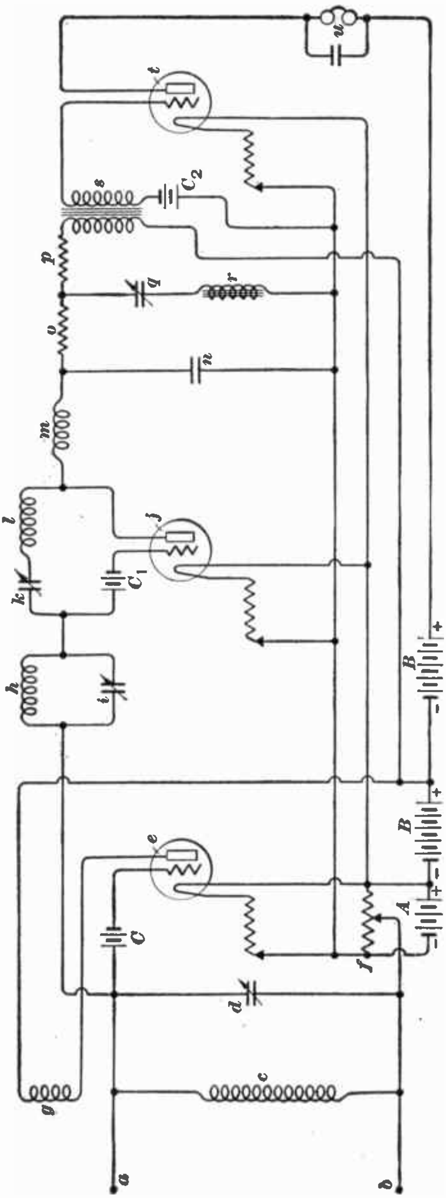


FIG. 11

22. The honeycomb coil *h*, Fig. 11, of 1,250 turns and its shunt condenser *i* of .001-microfarad maximum capacity controls the frequency of the positive and negative resistance reversals of the amplifier circuit of tube *e*. The primary function of tube *j* is to generate the oscillations, at a frequency above audibility, that are impressed on the circuit of the detector tube *e*. A grid bias is secured for tube *j* by the battery C_1 to give a small bias, say, 3 volts effective.

The variable condenser *k* with a maximum capacity of .001 microfarad, in series with a honeycomb coil *l* of 400 turns or less, forms a coupling between the plate and grid circuits of tube *j*. The honeycomb coil *m* has 1,500 turns, and is mounted so that there is no coupling between it and either coil *h* or *l*. The .005-microfarad condenser *n* is simply a by-pass condenser and is not variable. The two resistance units *o* and *p* each have values of 12,000 ohms, non-inductively wound. The variable condenser *q* should have a maximum capacity of .0005 to .001 microfarad. The iron-core choke coil *r* has an inductance of .1 to .2 henry. A Ford spark coil serves very well, or a coil may be wound of about 650 turns of No. 26 or 27 B. & S. gauge double-cotton covered magnet wire on a ½-inch square core of thin sheets of iron. The combination of the resistances *o* and *p*, the condenser *q*, and the inductance *r* forms a filter that is used to keep the high-pitch hum out of the circuit where it is not wanted.

The audio-frequency transformer *s* is of the usual type connected essentially as in other circuits. The tube *t* operates as an audio-frequency amplifier. If the plate voltage from the *B* battery is about 90 volts, which is suitable for most tubes, a grid battery C_2 of about 4.5 volts should be used. The telephone receivers *u* should be shunted by a fixed condenser of .002 to .005-microfarad capacity to by-pass the high-frequency pulsations.

23. It is well to summarize the various functions of the tubes and their special contributing circuits. The high amplification takes place in the circuits of the first tube *c*, Fig 11. The tube *j* and its oscillating circuit alternate the positive and negative resistance conditions of the first amplifier circuit of tube *c*. The oscillating current from tube *j* and its circuit should be at about the upper range of audibility, say above 20,000 cycles per second. The filter system comprising the two resistances *o* and *p*, the condenser *q* and inductance *r* prevent the high-frequency current generated by tube *j* from producing objectionable sounds in the receivers, and from feeding so much energy into the tube *t* as to prevent its functioning. For convenience in making adjustments, it may be well to leave out the filter system until the rest of the set has been put in working order. The amplifying transformer *s* and tube *t* act as any ordinary audio-frequency amplifier.

This set is somewhat harder to tune than are some other types, but this is compensated for by the superior signal strength. Sometimes it is difficult to eliminate the high-pitched note, although with proper adjustments and apparatus this should scarcely be noticeable. As a general procedure, coils *c* and *g* should be closely coupled, more so than is usual in the ordinary regenerative sets. A pair of telephone receivers, connected for testing across condenser *k*, should give a hissing sound if the set is functioning. If no such sound is heard, it is advisable to check all connections, and check the battery polarities. It may be necessary to reverse the connections to coil *g* so it will have the proper coupling with coil *c*. Condenser *d* should be varied over its range of settings until the desired station is received. The condensers *i*, *k*, and *q* require an adjustment to give the loudest signal, and when once set need not be changed except for a casual check to see that they have not been disturbed. After the set is operating, it may be well to experiment with the various *C*, or grid, batteries until the best values are obtained.

COMBINATION CIRCUITS

24. Possible Circuit Combinations.—Many of the principles used in the standard and special circuits may be arranged to form certain combinations. The regenerative receiver may be combined with one stage of radio-frequency amplification, and followed by one or more stages of audio-frequency amplification. The radio-frequency regenerative receiver may also be reflexed, so that the radio-frequency amplifier tube acts also as an audio-frequency amplifier. Many of the special circuits may be used as tuners in various other combinations.

These are theoretical considerations. In practice it is found that not all of the special circuits will function well unless certain precautions are taken and various modifications are made. To illustrate the possibilities of combining various principles in designing a receiving set, a two-tube circuit, shown in Fig. 12, using tuned radio-frequency amplification, regeneration, reflex, and neutrodyne principles will be considered.

25. Roberts Circuit.—The Roberts receiver combines several well-known principles in a very practical way. It is shown schematically in Fig. 12. The radio-frequency transformer *a* is tuned to the desired wave-length by means of the variable condenser *b*. The primary, or antenna, coil is loosely coupled with the secondary coil. The tube *c* amplifies the signal at radio frequency. The amplified signal then passes through the tuned radio-frequency transformer *d* to the detector tube *e*. The transformer *d* is tuned by the condenser *f*. A suitable grid condenser and grid leak are provided at *g* to aid the detector tube to perform its duty.

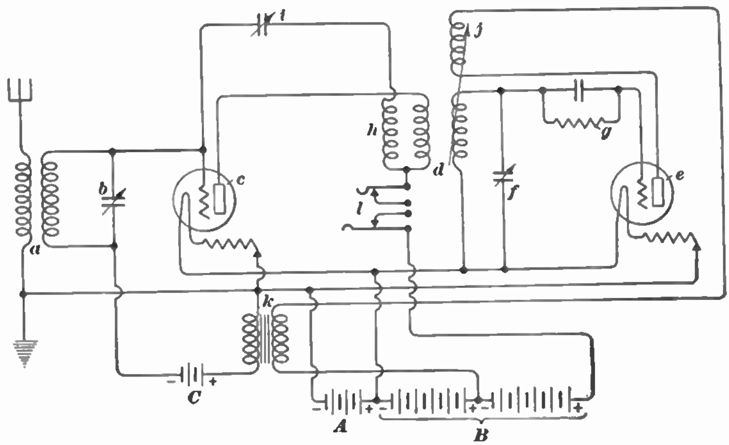


FIG. 12

The transformer *d* has two additional windings besides the usual primary and secondary. The neutralizing winding *h* is wound in parallel with the primary winding. The lower end of this winding is connected to the amplifier battery, the same as the primary winding. The upper end of the neutralizing winding *h* is connected to the small variable condenser *i*, from where the connection is extended to the grid of the amplifier tube. The tickler coil *j* is also a part of the transformer *d*.

The output of the detector tube passes through the audio-frequency transformer *k*, and is then delivered into the grid circuit of the tube *c*. This tube amplifies the signal at audio frequency, and the output is utilized to convert the signal into sound. The jack *l* is used to connect the telephone receivers or loud speaker in the plate circuit of the amplifier tube. The intensity of the audio-frequency signals may be further increased by adding one or more stages of audio-frequency amplification. The primary winding of the first additional audio-frequency transformer may be connected to the free springs of jack *l*. The *A*, *B*, and *C* batteries are connected as shown. The amplifier plate voltage should be 90. The *C* battery may be of the 6-volt type, tapped at each $1\frac{1}{2}$ volts.

26. The transformers *a* and *d*, Fig. 12, may be of any type that is most suitable to the experimenter. Spider-web coils have given very satisfactory results and the construction of these will be given in detail. The primary coil of transformer *a* may be a fixed coil of 15 turns, or it may consist of 30 turns tapped at every fifth turn. The spider-web form for this as well as for all the other coils here to be described has an inner ring $1\frac{7}{16}$ inches in diameter. Thirteen spokes are placed around this ring, equidistant from each other. The wire is wound on one side of two spokes, then on the other side of the next two spokes, and then passed from one side to the other until the required number of turns has been wound. The secondary winding has 45 turns. The primary and secondary windings are separated $\frac{1}{4}$ to $\frac{1}{2}$ inch.

Coil *h* and the primary of transformer *d* are wound on one form. The two wires are wound simultaneously, and side by side; one of these is used for the primary and the other for the neutralizing coil. Each of these windings requires 22 turns. The secondary of transformer *d* has 45 turns. The tickler coil *j* has 10 turns. All the coils are wound with No. 22 double-silk or double-cotton covered wire. The coil *h* and the primary of transformer *d* may be wound with No. 26 double-silk covered wire.

Condensers *b* and *f* are of .0005-microfarad maximum capacity. The small condenser *i* may be of the type used in neutrodyne sets, or a two-plate vernier condenser may be used.

SHORT- AND LONG-WAVE RECEIVERS

27. Most of the receiving sets here described have a wave-length range from 250 to 550 meters, which covers practically all the broadcasting wave-lengths. For longer wave-lengths the tuner must be either loaded or redesigned. The coils will require a greater number of turns to obtain the increased inductance. The condensers may or may not be changed, as satisfactory increases in wave-length may be obtained by increasing the inductance alone.

For the shorter wave-lengths, the electrical values of the coils and condensers must be correspondingly decreased. On extremely short wave-lengths, such as 5 to 10 meters, extremely small condensers are required. It may even be necessary to reduce the distributed capacity of the set by a rearrangement of the parts to operate it at such low wave-lengths. The length of the antenna must also be reduced to permit of tuning the antenna circuit to so low a wave-length.

PORTABLE SETS

28. Practically all receiving sets are portable in that they can be carried from place to place. The name portable, however, is more applicable to sets that are entirely self-contained and are especially intended for use under more adverse conditions than the non-portable sets. Portable sets must be of rugged construction, compact, and of fairly light weight. The same circuits that are used in the construction of non-portable sets may be applied to portable sets. The individual devices must be selected with care, consideration being given to their weight and their rugged construction. The vacuum tubes should be of such a type that no bulky storage battery need be carried. Either loop or trailing wire antennas may be used.

SELECTION OF APPARATUS

WELL-DESIGNED APPARATUS

29. Special consideration is necessary in the selection of almost all apparatus that goes into a radio set. There are many points of value to the purchaser of either parts or complete sets. Some of the really important characteristics of radio parts and devices as well as complete sets can be determined only by exhaustive tests. Owing to the difficulty of making such tests it is often hard to select a well-designed or low-loss instrument. In most cases there are certain features of design and construction to watch for. If these are up to standard it is generally safe to assume that the whole device is made right. There are always some manufacturers who attempt to copy the appearance of really good design features, but they may put out an otherwise inferior product.

CONDENSERS

30. Poor design and inferior materials in condensers have made many types unsuitable for radio work. The defects were chiefly evident as losses in actual operation. which losses would not be apparent except by careful test. In the zeal for production many condensers were made, and in fact still are. that had a poor quality of insulating material as the supports between plates. The energy handled by the tuner in a radio receiving set is very minute. and inferior apparatus will needlessly waste some of it. A condenser in particular can be made so as to have very little loss of energy in its part of the circuit. and should be able to tune the circuit very sharply.

Each time a condenser charges or discharges, the amount of energy represented by this charge must distribute itself equally over all of the plates. The resistance losses of a condenser depend partly on the opposition offered to the passage of these electric currents through the metal of the plates. To reach the plates. especially those most distant from the binding posts, it is necessary for the currents to pass through several metal-to-metal contacts, usually washers, and the supporting edges of the plates. Thus there is apt to be an appreciable resistance between the plates and terminals, especially after there is chance for oxides or rust to form, or contacts to work loose. Well-soldered or other permanent connection of all the plates represents very good construction, as the resistance is not apt to change with service. Therefore the plates and leads or posts should be made of some material that has a fairly low resistance.

There is a relatively large voltage change across the terminals of the condenser. This voltage attempts to send current across or through the insulating material that separates the plates, or, more properly, that supports the rotary plates. There is air, in most cases, between the plates, and some sort of rigid insulating material placed so as to hold the stationary and rotary plates apart. If this rigid supporting material has any leakage or other loss, it represents an actual loss of energy that may be very serious in a radio receiving set.

31. The well-designed condenser should have a permanent electrical connection between all the plates in each group; that is, the stator and the rotor. The connection from the rotor plates to the binding post for that group should be by means of a flexible copper braid, or pigtail connection, as it is called. It is hardly satisfactory to depend on a movable contact between the shaft and a sleeve, although some types give very little trouble from this source. The plates should be of fairly heavy aluminum or preferably brass, as the latter holds its shape better. There should be bearings at each end of the rotor shaft to keep it securely aligned.

The insulating material that forms the rigid support between the stator and rotor plates is of the greatest importance. In the first place, the quality of material is very important, as this is one of the most fruitful sources of losses in condensers. A good material will introduce very low losses with radio-frequency currents, and will maintain that characteristic indefinitely, but inferior materials will introduce relatively higher losses. The supporting material must also be rigid enough to hold the plates permanently in their relative positions. Also, this insulating material should be so placed that the losses due to the absorption of energy in the insulating material are small.

32. The more important features to look for in a superficial inspection of a condenser are the material and construction of the plates and the rigid insulating material. The use of separate vernier plates is not very satisfactory in practice, unless extremely well designed. Where fine control is desired, it is best to employ some sort of vernier control that will move all the plates in minute amounts. This may be a separate specially designed vernier dial, or a reduction gear of some sort built into the condenser. Variable condensers with dielectrics other than air, such as mica, are not generally satisfactory in radio-receiver tuners.

Fixed condensers are made in many sizes and styles. In this field mica is unrivalled as a dielectric material. It makes a compact condenser, and one that remains constant in value. Copper or tin-foil makes good plate material, as it can be made into a compact unit with the mica spacers. The whole unit should be rigidly clamped between thin sheets of insulating material of good quality. Fixed condensers are most commonly used in lower-frequency circuits or are often shunted by high resistances, so the feature of leakage and other losses, while important, is not such an essential consideration. Inferior materials, such as paper, are not very suitable as dielectric materials, owing chiefly to their tendency to absorb moisture.

COILS AND TUNERS

33. Coils for radio purposes have universally been wound on some form of insulating tubing. This represents a fairly easy and convenient way to wind the wire in coil form and have it stay in place. Double-silk or double-cotton covered wire is used in a majority of cases. Sometimes, a binder like collodion is used to keep the individual turns of wire in place.

More recent practice tends to use shorter coils as a means of saving space. These take the form of bank, honeycomb, and many other types of winding. Even with these types of windings there are considerable losses, particularly with some types of binder compounds that are used too freely. The insulating materials, besides air, tend to introduce some losses into the coil, which also tends to broaden the tuning.

Coils, for best results, should have a minimum of insulating material besides air, and the nearer the material is to the characteristics of air the better. Materials should not be employed that collect moisture or dirt easily and thus do not have constant characteristics. Neither should the insulation be so scant as to permit the windings to move about, or what is worse, to form short circuits of contacts between turns. Variometers also should be so designed as to have a minimum of insulating material adjacent to the windings.

Tuning coils were formerly made with a generous supply of insulating material, particularly in the coil form. Another extreme is the use of heavy wire, and very little, if any, insulating material. The wire is often so heavy or large in size as to be self-supporting. One convenient way of winding is the so-called *basket-weave* style. Although the cross-section of the wire is much larger than is necessary for low-frequency currents of equal magnitude, it seems to offer very little opposition to the radio-frequency currents that travel on the surface. However, the losses from this source are quite low and excessively large wire sizes should not be necessary. Taps on coils and tuners are often sources of trouble and should be eliminated so far as possible. Pig-tail connections should be used between any movable coil and its fixed binding posts or terminals.

SOCKETS

34. Although considered the most reliable pieces of apparatus in a radio set, the sockets are really one of the most sensitive and troublesome. The small received energy must pass through the sockets, and if they are made of inferior materials leakage of energy will occur. The socket has an important function to perform in the transfer of energy from the receiver circuit to the tube and back again. Any losses caused by defective contact springs or other sources are very undesirable. The contacts are apt to become dirty after the set has been in use for some time, which will introduce losses that are hard to locate. Polishing the contact springs with a small piece of sandpaper will help conditions in the socket. If the base pins on the tube base are badly corroded, they too should be cleaned with fine sandpaper.

Some sockets that have good insulating material have a large surface that collects dust, thereby causing leakage. No dust or dirt should be allowed to accumulate on or near the tube sockets, or, for that matter, anywhere in the radio set. Side-wiping springs in the socket are good, as they make contact over a relatively large part of the base pins. The quality of the insulating material and the effectiveness and type of the contact springs are the main considerations in a radio socket. The location of the contact terminals or binding posts is a feature of convenience in wiring a set.

Adapters for mounting one type of tube in a socket designed for a different type of tube are sometimes very useful and fill a certain demand. Unless absolutely necessary, however, adapters should not be used, as they will certainly introduce losses into the set. The contact springs are the troublesome features in adapters, and this feature should receive close inspection.

TRANSFORMERS

35. The actual design of transformers is more of a problem and requires more care than is shown by many types on the market. The quality or grade of iron of which the laminations are made is of extreme importance in determining the operating characteristics of a transformer. The iron becomes magnetized and demagnetized with every bit of energy that passes through the transformer. If of too thick sheets of iron, called *laminations*, and if not of the proper grade, the iron will take a considerable amount of energy out of the circuit that will be used up in the iron as losses. The iron circuit is also important in producing amplification without introducing distortion.

The windings of the transformer perform the functions of receiving and sending on the energy from one tube to the next in the set. Several of the important characteristics of the windings and of the transformer as a whole have been considered elsewhere. Briefly, the spacing of turns as determined by the insulation, and the number of turns are of vital importance in determining the impedance of a transformer, which is its characteristic that is of most importance.

36. With transformers probably more than with any other piece of radio apparatus, one must rely on the integrity of the manufacturer. In general appearance, the transformer should be well-proportioned, and should represent a finished job. The laminations should be of thin iron rigidly clamped together. The coil, or winding, should be impregnated with a good insulating compound to give solidity to the coil and make it reasonably waterproof. The lead wires should be quite rugged and connected with conveniently located binding posts, or terminals. Rigid mounting posts or feet should be provided in a convenient location.

The foregoing discussion applies in general to both audio- and radio-frequency transformers. Audio transformers carry currents of relatively low frequency and in larger amounts, so are more rugged and larger than are radio-frequency transformers. Some manufacturers place a protective shell over part or all of the transformer assembly of audio-frequency transformers, which is of a good protective feature. Radio-frequency transformers are ordinarily so delicate as to require a protective case or shell, sometimes partly or wholly of metal, but more commonly of an insulating material. The terminals, or binding posts, are then mounted directly into this shell with all connections of fine wire on the inside. In general, radio-frequency transformers have air cores if designed for sharp tuning, and a partial iron core if designed for a broader wave-length range.

PANEL MATERIALS

37. Any good insulating material may be used as a panel for a radio set. Dry wood makes just as good a panel as any other material, but should be treated so as not to be affected by moisture. It has the advantage that it can be finished in nearly any style possible to wood surfaces. Added to that, it is very easy to drill and relatively inexpensive though liable to crack if made very thin. Despite its many advantages, wood has not come into very extensive use as panel material.

The electrical characteristics of the panel material should be the first consideration in the selection of a panel for a radio set. However, this is not as important as it might be, for in a properly designed set the radio- and audio-frequency currents should be kept away from the panel to a very large extent. The panel should preserve its electrical properties with the usual atmospheric variations. Surface resistivity or the resistance along the surface of the panel is one of the most important properties in actual practice. Ordinarily this resistance is so high as to prevent any loss of energy along the panel, even with high-voltage terminals located close together.

Mechanically the panel should be able to withstand a reasonable amount of handling and working. If too brittle it will break easily, and if too soft it is not apt to hold its shape permanently. It should be soft enough to work and drill with clean-cut edges. While the finish is important from the point of view of appearance, it is not likely to affect the panel's ability to perform its other functions. However, the panel should retain its finish and shape indefinitely.

The various phenolic and other similar materials make very good panels for radio service. These materials can be obtained in convenient thickness and sizes. They conform with the usual electrical and mechanical requirements, and present a fine appearance.

HINTS ON BUILDING SETS

PLANNING OF SET

38. Selection of Circuit.—The construction of a radio receiving set is not a difficult matter, and any one capable of handling a few simple tools should be able to assemble a satisfactory outfit. The first step in the construction of a set is the selection of a suitable circuit. This selection is governed largely by the ultimate requirements of the set, and by the amount of money available for the expenditure of parts. The experimenter should not sacrifice the quality of the apparatus for the quantity. It will be to his advantage to build a simple set of first-class parts rather than a more elaborate set of inferior parts.

In many instances it may be desirable to start with a simple inexpensive set and gradually build it up. In this case the experimenter must select a suitable preliminary circuit, one that is capable of being modified and enlarged without discarding any of the existing apparatus. The panel, the base board, and the cabinet should be large enough for the ultimate requirements of the set.

39. Lists of Parts.—The circuit diagram will be of help in making a list of the required parts. It may be of advantage to draw a wiring diagram and on it show all the devices required in the completed set. This will include all the binding posts, tube sockets, subpanels, and so forth. The experimenter then lists one by one the different parts, writing beside each item the individual requirements of that part. The electrical values of all coils, condensers, grid leak, and batteries should here be included. The dials or knobs for turning the rotors of coils, condensers, and rheostats should not be forgotten.

The size of the panel is the last item to be considered. It may be of some advantage to procure all the parts, and arrange them temporarily in the same positions that they will occupy in the completed set. The space occupied by the parts may then be measured, and this will serve as a guide both for the size of the panel and of the cabinet. In purchasing a panel, a standard size should be selected which may be somewhat larger than that actually required in the set.

LAYING OUT OF SET

40. Arrangement of Parts.—Arrange the parts of a receiving set in such a way that the wiring will be as short and as direct as possible. This does not mean that the apparatus should be crowded. On the contrary, the parts must be so placed that there will be no electrical interaction between them, thus reducing the electrical losses to a minimum. Coils should not be any nearer than 2 inches to condensers, and at least 1 inch away from the panel. Audio-frequency transformers must not be too near each other; their cores should be at right angles.

The arrangement of parts shown in Fig. 6 may serve as a guide in building other sets. The peculiar construction of the vario-coupler makes it possible to place it near the panel. The condenser is several inches away from the vario-coupler. The cores of the audio-frequency transformers under certain conditions should be at right angles to each other. This set might have been arranged more suitably by mounting the socket *m* behind socket *l*, and the jack *p* nearer the rheostat *o*. This would reduce the size of the panel, and at the same time give a more pleasing effect on the front of the panel.

41. Drilling of Panel.—The panel on which the control devices are mounted is made of a good insulating material, like rubber or bakelite, and is usually an appreciable item of expense in the ordinary receiving set. Great care must, therefore, be taken to arrange the apparatus properly, to determine the exact positions of the different pieces, to make the correct markings, and, finally, to drill the panel properly.

One possible layout of a panel is shown in Fig. 13. The drawing is made on a sheet of heavy paper of exactly the same size as the actual panel. The panel layout here considered is intended for the combination set shown in Fig. 12.

The panel, Fig. 13, is 14 inches long and 7 inches wide. On it are mounted two condensers, two rheostats, the tickler control, and the jack. The two condensers are mounted at the extreme ends of the panel as indicated at *a* and *b*. The dial that regulates the tickler coil is mounted in the center, as shown at *c*. The rheostats are mounted on either side of the tickler-coil control, as indicated at *d* and *e*. The jack is mounted

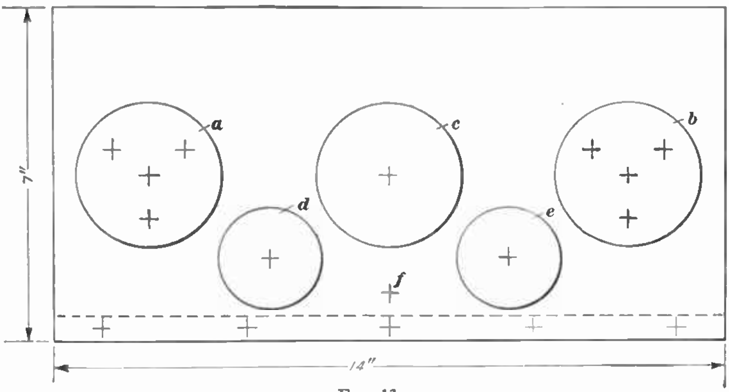


Fig. 13

at *f*. The dials and other controls may be placed directly on the panel and their positions varied until the desired effect is obtained.

42. The sheet of paper that is used for marking the locations or positions of the different devices is called a template. In Fig. 13, circles are drawn for the three control dials, in the exact locations that these will occupy on the actual panel. The circles are of the same diameter as the actual dials. Care should be taken that the centers are located in a straight line, if such an effect is desired. When the different pieces have been properly located and their positions marked, it is necessary to locate the holes that are required for fastening the apparatus to the panel. These are designated as + in the figure, the intersection of the two lines indicating the exact center position of the hole. Aside of each cross is marked the size of the hole that is to be drilled in that location. The crosses below the dotted line show the locations of the holes necessary in fastening the panel to the baseboard. Extreme care should be taken to mark the locations accurately. For flat-head screws the holes are countersunk, so that in the finished set the head of the screw is flush with the panel.

43. When all the markings have been carefully made, the template is placed over the actual panel and securely fastened to it by means of clamps or by using a small amount of paste on the four corners. The holes are then located on the panel by punching through the template with a center punch and a light hammer. The template is then removed and if any of the markings on the panel are not clear, the center punch is used until the markings are distinct and clear, and sufficiently deep that the drill will take hold. Holes of the proper size are then drilled in the panel. The holes that take flat-head screws are countersunk with an ordinary wood countersink held in a bit brace.

When the panel has been properly drilled, it is fastened to the baseboard by means of flat-head screws. The different pieces are then mounted on the panel. The apparatus that is mounted on the baseboard should be arranged properly with reference to that on the panel, and securely fastened to the baseboard.

If a subpanel is required in the set, it is marked and drilled in the same manner as the front panel. Subpanels are used for mounting the antenna and battery binding posts, tube sockets, and many of the other pieces found behind the front panel.

WIRING OF SET

44. The set should be wired with regular bus-bar wire. In its absence ordinary No. 14 copper wire may be used. It is advisable to begin the wiring with the filament circuit. All connections should be soldered with rosin-core solder. No acid fluxes should ever be used in a receiving set. All wires that are fastened to binding posts should have the ends neatly made into loops so that the contact surface between the wire and the post is as great as possible. If bare wire is used, the greatest care should be taken that any crossing wires do not touch each other. It may even be necessary to use varnished cambric tubing (spaghetti) on the wires to prevent short circuits.

The connecting wires are neatly bent, all corners being sharp and square. This will give a very good appearance to the set, especially if the arrangement of the parts is satisfactory.

TESTING AND TROUBLE HUNTING

45. General Testing.—When the set has been properly assembled and wired, and all the outside connections have been made, it may be tested out by listening to the strong signals of a nearby transmitter. The set may operate satisfactorily, but the chances are that it will not at first give the expected volume or clearness. If the set does not operate, or if the signals are not as strong as they should be, the wiring and the connections should be checked in accordance with the wiring diagram. All the binding-post connections should be tested to see that the wires are in firm contact with the posts. In many cases by reversing the connections on the coils or transformers an improvement is made in the operation of the set. Frequently one wire comes in contact with another, causing a short circuit, which makes the set inoperative. More specific troubles and their remedies will be considered in the following articles.

46. Battery Troubles.—The batteries are the essentials of a vacuum-tube receiving set. The *A* battery supplies the current that heats the filaments of the tubes. Hence if the filaments of the tubes do not light when the circuit is apparently completed, the trouble may be found in a run-down *A* battery or in the connections. The *A* battery may be tested with a hydrometer if of the storage type, or with an ammeter if of the dry-cell type. The circuit should then be traced through the wiring, connections, rheostats, and vacuum-tube sockets.

The *B* battery should also be tested for voltage, and all the connections carefully examined. Loose connections are the cause of weak signals or breaks in the signals. No signals will be received if the *B*-battery terminals are reversed. The *B* battery is tested with a voltmeter, and provision should be made to have the correct voltage on the plates of the tubes.

47. Tube, Socket, and Rheostat Troubles.—When it is known that the *A* battery is good and the filaments of the tubes do not light, the trouble may be traced to the wiring, the rheostat, the socket, or to the filament itself. If the filament is broken or burnt out a new tube must be substituted for the defective one.

The rheostat may be tested for continuity by connecting it in series with a dry cell and a pair of telephone receivers. If no click is heard when the circuit is completed or broken the rheostat is defective. This defect should be remedied or a new rheostat substituted.

The contact springs in the sockets should make a firm contact with the prongs or terminals of the vacuum tube. By bending the offending springs upwards, the springs may be brought into firmer contact with the tube terminals.

48. Coil and Transformer Troubles.—Coils as well as transformers may have an open winding or a short-circuited winding. The connections to these devices may be defective, thus introducing either a high resistance or an intermittent break into the circuit. The wrong values of inductance may have been chosen for the coils, requiring either a greater or a smaller number of turns. Tuned radio-frequency transformers are susceptible to the same faults as ordinary inductance coils.

Fixed radio- and audio-frequency transformers must be judiciously chosen for the various functions that they are to perform. Radio-frequency transformers should be capable of acting efficiently over a reasonable wave-length range. Audio-frequency transformers should be selected according to their step-up ratio for a given stage in the circuit.

TABLE I

TROUBLE IN DETECTOR CIRCUIT

Trouble	Circuit	Probable Cause	Remedy
Weak Signals	Antenna Circuit	Wrong values of condensers or inductances.	Use values recommended.
		Bad insulators.	Use standard insulating material.
		Something touching the aerial or lead-in.	Keep aerial away from house or trees.
		Ground disconnected or contacts oxidized.	Check over connections and solder if possible.
		Bad contacts in condensers or switches.	Scrape all connections and pigtail all moving contacts if possible.
	Grid Circuit	High resistance in the circuit, due to bad contact.	Check over circuit and see that all connections are tight.
		Losses due to dust between plates of variable condensers.	Clean plates with a cloth or pipe cleaner.
		Wrong value of grid condenser or grid leak, or defective vacuum tube.	Use values recommended. Should be .00025 mfd. condenser and for most circuits, a 2-megohm leak.
	Filament Circuit	Batteries discharged.	Test with voltmeter and replace or recharge as necessary.
	Plate Circuit	Insensitive or demagnetized telephone receivers.	Reverse phone connections. Usually it is best to buy new phones.
		Disconnected or broken lead in telephone cord.	New receiver cord will be necessary.
		Wrong value of by-pass condenser.	Use values recommended.
		B battery discharged.	Test with a voltmeter; and if the voltage is down, replace or recharge.
		Wrong polarity or number of turns on tickler coil.	Reverse tickler connections.
Intermittent Signals	Antenna Circuit	Aerial swinging in the wind, and touching tree or other object.	This can be remedied by placing insulator or guy wires at points where rubbing takes place.
		Lead-in touching the house.	Same as above.
		Ground disconnected from ground plate or water pipe, touching it intermittently.	Scrape bright and shiny, and solder if possible.
		Wire not making good contact with binding post.	Scrape wire bright and shiny, and screw binding post down tight.
	Grid Circuit	Bad contact in switch and switch points.	Scrape bright and shiny.
		Disconnected leads from coil to switch points.	Test for open circuit with dry cell and phones.
		Variable - condenser plates touching.	Straighten plates.
		Broken pigtail connection.	Replace and solder.
		Too high a value of grid leak or condenser.	Use values recommended. Should be .00025 mfd. condenser and for most circuits, a 2-megohm leak.

TABLE I—(*Continued*)

TROUBLE IN DETECTOR CIRCUIT

Trouble	Circuit	Probable Cause	Remedy
Intermittent Signals	Filament Circuit	Tube shaking in socket, making bad contact with socket.	Bend up springs so that tube makes perfect contact.
		Bad contact in rheostat, discharged or defective filament battery.	Tighten or solder connections, and recharge or replace filament battery.
	Plate Circuit	Defective B battery.	Test with voltmeter to see if voltage is down. Replace or recharge.
		Bad contact or loose binding post.	Tighten or solder connections.
		Diaphragm of telephone receiver bent, or not adjusted.	If bent, a new diaphragm will be necessary. If adjustable, readjust.
		Defective by-pass condenser.	Test for short circuit with dry cell and phones. If shorted, replace.
No Signals at All	Antenna Circuit	Broken lead-in or ground connection.	Reconnect and solder if possible.
		Aerial down or touching grounded object.	Replace and insulate at points where grounding takes place.
		Broken wire in coil or condenser contact due to corrosion.	Test for short circuit. Solder wires and create contact again.
		Defective lightning arrester.	Replace.
	Grid Circuit	Broken wire or connection, due to corrosion.	Scrape contacts bright and shiny, and solder if possible.
		Short-circuited condenser.	Test for short circuit with phones and dry cell.
		Defective grid condenser or grid leak.	Test for short circuit with phones and dry cell.
		Bad contact between grid prong of the tube and socket.	Bend up spring contact in socket.
	Filament Circuit	Discharged A battery.	Test with a hydrometer, and recharge or replace if necessary.
		Defective vacuum tube.	Replace.
	Plate Circuit	B battery connections reversed.	Check connections. Positive side of B battery always goes to the plate.
		Discharged or short-circuited battery.	Test with voltmeter or hydrometer, and recharge or replace if necessary.
		Phones disconnected or short-circuited.	Connect phones. Do not let tips touch each other.
		Punctured by-pass condenser.	Test for short circuit with dry cell and phone.
		Open circuit between plate of the tube and filament circuit.	Connect phones. If no noise is heard when connection is made, go over the connections and tighten.

49. Troubles and Remedies.—It would be practically impossible to enumerate all the troubles that may be found in receiving sets. Every set has its peculiarities and these must be taken into consideration when a search is made for faults that interfere with the reception of signals. Some of

TABLE II

TROUBLE IN AMPLIFIERS

Circuit	Trouble	Probable Cause	Remedy
Radio-Frequency Amplifiers	Continuous Oscillations	Plate or B voltage too high.	Use values recommended by tube manufacturers.
		Potentiometer wire broken or disconnected on the positive side.	Check connections and solder.
		Leads too long or crowded, causing feed-back.	Rearrange parts and rewire, keeping grid leads as short as possible.
		Apparatus crowded, causing same effect.	Same as above.
	Weak or No Signals	Batteries discharged.	Test with a voltmeter or hydrometer, and replace or recharge if necessary.
		Defective tubes.	Replace.
		Potentiometer wire broken or disconnected on negative side.	Check and tighten all connections.
		Transformer winding open or short-circuited.	Check for open circuit with dry cell and phones.
Audio-Frequency Amplifiers	Howling or Whistling	Plate voltage too high.	Use value recommended by tube manufacturer.
		Secondary circuit open.	Test for open circuit with dry cell and phones.
		Burned out or short-circuited transformer winding.	Test for open circuit with dry cell and phones.
		Too high a ratio transformer. Distorted signals.	Use lower ratio transformer.
		Transformers too close to each other, or not at right angles.	Rearrange and rewire.
		Wrong connections.	Check connections.
		Parallel connections causing feed-back.	Keep grid lead away from plate lead, and as short as possible.
	Weak or No Signals	Batteries discharged.	Test with a hydrometer or voltmeter, and replace or recharge if necessary.
		Defective tubes.	Replace.
		Open or short-circuited windings.	Test for open circuit with dry cell and phones.
		Wrong connections.	Check connections.
		Bad contact.	Scrape bright and shiny, and solder.

the more common troubles are enumerated in Tables I and II, including the circuit in which the trouble exists, the probable cause and the remedy.

Many other factors may interfere with the proper reception of signals. Some of these may be due to the design and construction of the set or in the connections to the set. Other factors may be entirely outside of the set. Static, sparking commutators on commercial machines, nearby regenerative sets—all these are troubles that can be overcome only with the greatest difficulty.

COMMERCIAL RECEIVING SETS

GENERAL INTRODUCTION

50. Commercial radio receiving sets vary greatly in design, appearance, and operation. It is hardly necessary to add that they vary considerably in the initial and the maintenance costs. Some receiving sets are scientifically designed, and represent the last word in refinements of a particular type of circuit; others fall short of this goal. The number of sets on the market is very great, and the number of circuits is quite large. Many of the distinctive circuits, so called, are merely some refinement or change applied to a more familiarly named circuit.

The sets here illustrated and described are fairly indicative of the wide field of radio receiving sets. They represent the main types that are in quite general use. The space limitations prevent the inclusion of many other worthy types of sets that are really meritorious in operation or that present some other feature of unusual interest. In many cases the manufacturer makes the same set, or practically the same, in different styles of cabinets, just to meet the demands of the purchaser. The following cases illustrate the tendency, which is a natural one, to incorporate features of artistic design into the exterior appearance of the complete receiver.

FEDERAL RECEIVING SET

THEORY

51. Each of the sets here described exemplifies one or more of the principles that have so far been considered. A practical application of radio-frequency amplification with fixed, or untuned, transformers is made in the type 141 receiving set of the Federal Telephone Manufacturing Corporation. A schematic diagram of this set is shown in Fig. 14. The antenna circuit has one tuning control and a compensator. The antenna compensator *a* consists of a switch arm that can be brought in contact with any one of five contact points. The contact points *1* to *4*, inclusive, are each connected to the antenna through condensers of different capacities, the size of the condenser used depending on the length of the antenna. When no compensating condenser is required, the switch arm of the compensator is moved to contact *5*. The antenna circuit is tuned by means of the variable condenser *b*. A variable coupling exists between the antenna inductance coil *c* and the secondary coil *d*. The secondary or grid circuit is tuned by means of the variable condenser *e*.

52. From the grid tuning circuit the signal is passed successively to the radio-frequency amplifier tubes *f* and *g*, Fig 14, the detector tube *h*, the audio-frequency amplifier tube *i*, and the power amplifier tube *j*. The vacuum-tube sockets and the radio- and audio-frequency transformers are placed in a brass case *k* and sealed. The tops of the vacuum-tube sockets project through the top of the case. Amplification is controlled by means of the potentiometer *l*. A .005-microfarad condenser *m* serves as a by-pass for the radio-frequency pulsations around a portion of the potentiometer *l*. A similar condenser *n* is placed in the circuit between the pointer of the potentiometer and the ground terminal.

The condensers *b* and *c* have metal shields interposed between the panel and the condenser plates. This is indicated

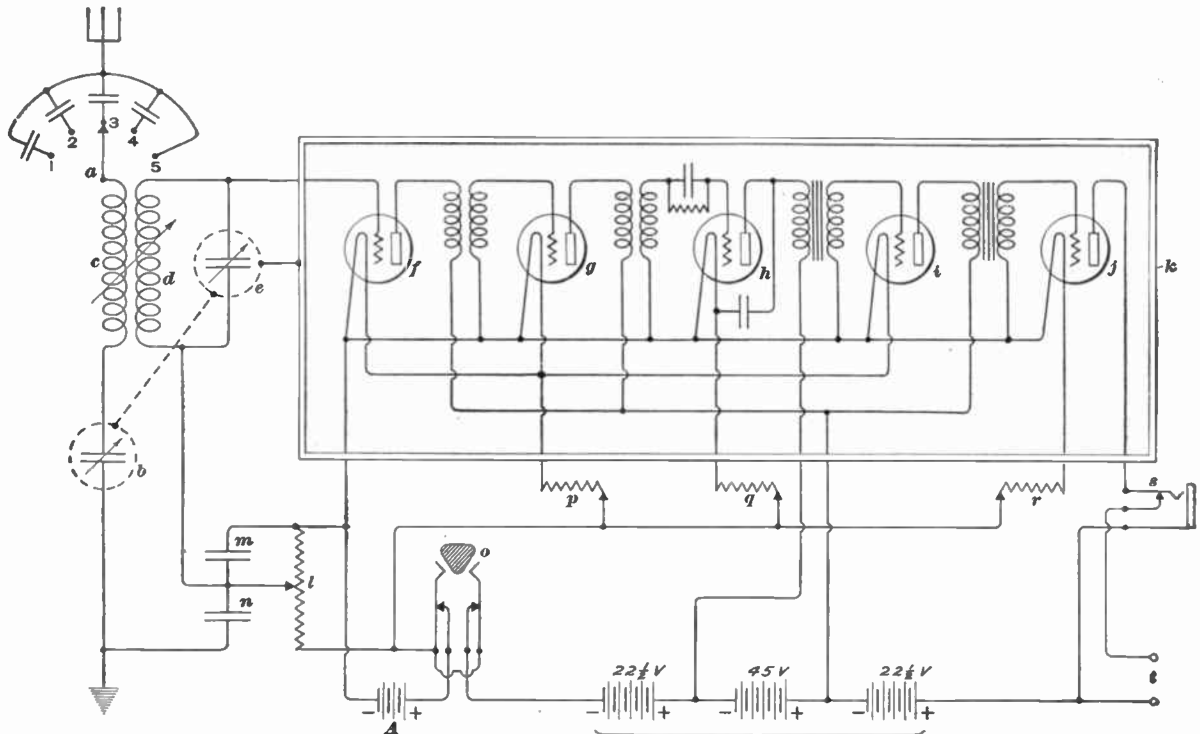


Fig. 14

by means of the dotted circles. The shields are connected to the ground terminal. The metal framework within the set as well as the brass case *k* are also grounded.

53. The *A* battery must be of a size suitable to operate the tubes in use. A battery switch *o*, Fig. 14, serves to disconnect the battery when the set is not in use. Three different rheostats are provided. The rheostat *p* controls the filament current of the two radio-frequency tubes *f* and *g*, and of the audio-frequency amplifier tube *i*. The rheostat *q* controls the filament current of the detector tube *h*. A separate rheostat *r* is needed for the second audio-frequency amplifier tube *j*, on account of it being a 5-watt tube requiring a higher voltage at its terminals.

The *B* battery is so divided that the detector tube has a plate voltage of 22½, the two radio-frequency tubes and the first audio-frequency tube 67½, and the power amplifier tube 90 volts or more.

In the actual set, connections are provided for a *C* battery, which may be used to limit the current in the plate circuit of the amplifier tubes.

A jack *s* is provided for telephone receivers, and the terminals *t* for a loud speaker.

CONSTRUCTION AND OPERATION

54. Construction of Federal Set.—The Federal type 141 receiving set is shown in Fig. 15 with the panel and the apparatus partly removed from the cabinet. The various controls on the front panel carry appropriate designations. The *Selectivity-Volume* control (top center) changes the coupling between the antenna and the secondary coils *a* and *b*. The *Antenna Wave-Length* dial (at the left) controls the antenna series variable condenser. The push button marked *Battery* (small button near bottom of panel) is part of the filament switch; when pushed in, it opens the *A*-battery circuit. The *Amplification Control* (lower center) is a dial on the shaft of the potentiometer, and controls the bias on the first radio-frequency tube. The telephone jack (lower right) carries the designation *Telephones*. The *Secondary Wave-Length* dial (at the right) is mounted on the shaft of the grid-circuit condenser and controls the frequency of that circuit.

On a subpanel inside the set are mounted the three rheostats with their controlling knobs shown at *c*, *d*, and *e*. The antenna compensator control switch is shown at *f*.

The vacuum tube unit is shown in Fig. 16. It is fastened to the metal frame of the set by means of small clamps and

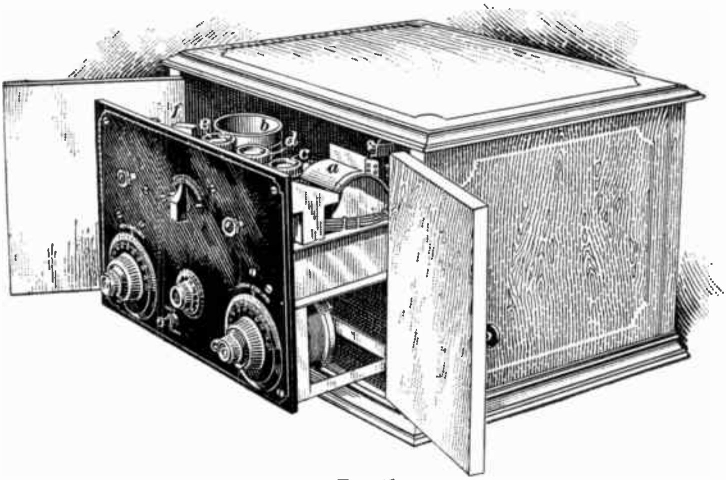


FIG. 15

supported on springs. The brass case is connected to ground through the springs and the frame of the set. The connections to the tubes and transformers are made by means of a number of leads extending from the case. These leads are connected to terminals on a panel in the rear of the set. The cabinet shown in Fig. 15 is one of a number of styles used to house this type of receiver.

55. Precautions Preparatory to Tuning.—Connect the antenna, ground, and loud-speaker wires to the proper binding posts. Special care should be taken to make the battery connections properly. Grasp the two octagon knobs, Fig. 15, near the top of the panel, pulling the receiver out as far as possible. Turn the three knobs, *c*, *d*, and *e*, as far to the left as possible. Insert tubes in their sockets, being certain that the detector is placed in the socket marked *Detector*. If a power tube is used it should be placed in the socket marked *2nd A. F.* These markings are above each socket. Insert telephone plug in the jack marked *Telephones* and adjust telephones to your head.

Pull out switch marked *Battery*. Rotate *Amplifier Rheostat e* and *2nd A.-F. Rheostat c* to the right until the filaments of the tubes that they control are burning at a visible glow. Repeat this operation with *Detector Rheostat d* if a U V 201A or C 301A tube is used as a detector. If a detector tube such as the U V 200 or C 300 is used, turn the *Detector Rheostat*

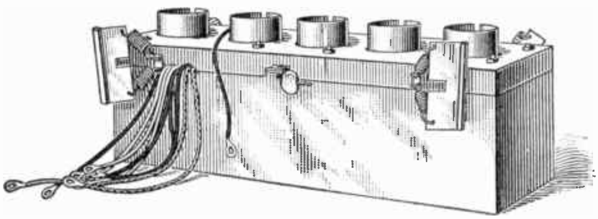


FIG. 16

to the right until a soft hissing sound is barely heard in the telephones. This tube will light very brilliantly, while the others will not. Because conditions vary with each installation it is important that the *Antenna Compensator f* be adjusted to change the electrical dimensions of the antenna to suit the requirements of the receiver.

Set *Selectivity-Volume* switch to extreme right, also *Amplification Control* as far to the right as possible, *Secondary Wave-Length* between *80* and *85* and *Antenna Compensator* at *1*.

Start *Antenna Wave-Length* dial at *0* and rotate slowly toward the higher numbers until a distinct click or rushing sound is heard. Note the dial setting where this sound occurs. If no click or rushing sound is heard, set the *Antenna Compensator* at *2* and repeat. This process should be repeated with each of the five *Antenna Compensator* settings. The setting of the compensator that produces the highest reading on the *Antenna Wave-Length* dial is the correct compensator setting for the antenna being used and will not need to be changed unless the receiver is used on a different antenna.

After the Antenna Compensator and Rheostats are adjusted, return the panel to its original position. These adjustments will not need to be made again unless antenna or tubes are changed.

56. Tuning.—Set *Selectivity-Volume* switch, Fig. 15, so that the pointer is at the extreme right of the scale; *Amplification Control* well to the left; *Antenna Wave-Length* at *10* and *Secondary Wave-Length* at *5*. Rotate *Amplification Control* to the right to a point where a click is heard in the telephones.

Turn the *Secondary Wave-Length* dial slowly forwards and backwards from *5* to about *20*. If no signal is heard, advance *Amplification Control* a little farther to the right and turn the dial slowly forwards and backwards from about *15* to about *40*. Continue this process, advancing the *Secondary Wave-Length* dial about twenty points each time the *Amplification Control* is advanced, and at each advance set the *Antenna Wave-Length* dial forwards five or ten points until the desired signal is heard (a signal is either voice, music, or a whistling sound). A signal of the whistling kind will, as the *Secondary Wave-Length* dial is rotated, vary from a shrill to a low weak note, and then back to a shrill one. Always stop the dial where the signal has the lowest note—never on the shrill note.

If the signal heard is a whistle, stop the *Secondary Wave-Length* dial in the position described above and turn the *Amplification Control* to the left until the whistle disappears and the music or voice is heard. Make fine adjustments with the vernier. The veniers are the small knobs in the center of the two wave-length dials.

Rotate *Antenna Wave-Length* dial slowly until the signal is heard with the greatest volume. Make fine adjustments with the vernier.

Should there be interference between the signals of two stations, set *Selectivity Volume* switch within four or five points of the center of the scale and make slight adjustment; first, with the vernier on *Secondary Wave-Length* dial, and then with *Amplification Control*.

A slight adjustment of the rheostats may improve the volume or tone quality of the signal. Always keep the rheostats turned as far to the left as possible without impairing the volume or tone quality of the music.

These tuning instructions apply not only to the Federal set but also to other sets of similar construction. The positions of the dials may vary with the different sets because the electrical values of the coils and condensers may be different. The general procedure, however, may safely be followed.

FRESHMAN MASTERPIECE

57. Circuit Diagram.—The Freshman Masterpiece is a five-tube tuned radio-frequency set manufactured by Chas. Freshman Company, Inc. The set consists of two stages of tuned radio-frequency amplification, detector, and two stages of audio-frequency amplification. In Fig. 17, the radio-frequency transformers *a*, *b*, and *c* are shown attached to their individual condensers by means of which they are tuned. The transformers are of special construction, and wound in such a manner that the losses are as small as possible. The radio-frequency amplifier tubes are placed in the sockets *d* and *e*, the detector tube in socket *f*, and the audio-frequency amplifier tubes in sockets *g* and *h*. The detector tube has a grid condenser and grid leak combination *i*, of which the grid leak is variable. A .002-microfarad fixed condenser *j* is connected across the primary winding of the audio-frequency transformer *k*. This transformer has a 5-1 ratio of winding, and the second audio-frequency transformer *l* has a 3-1 ratio. The jacks *m* and *n* are for telephone receivers and loud speaker, respectively. The 30-ohm rheostat *o* is individual to the detector tube. The 6-ohm rheostat *p* is common to all the amplifier tubes. A battery switch for opening and closing

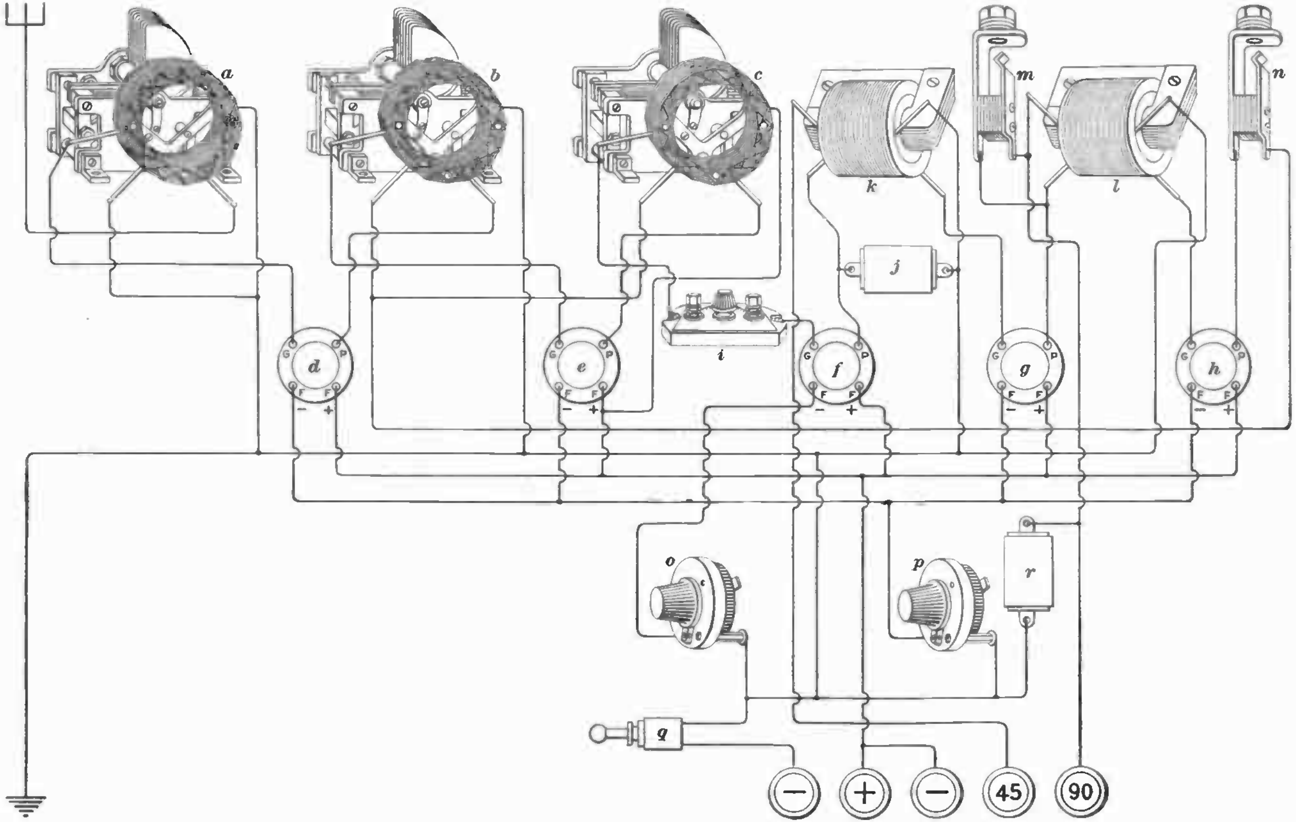


FIG. 17

the battery circuit is shown at *q*. The .006-microfarad condenser *r* is connected across the batteries to reduce noises and give smoother operation.

58. Tuning of Set.—The actual set, as shown in Fig. 18, has three large dials that are mounted on the shafts of the condensers. The rheostat knobs are designated *Detector* and *Amplifier*. The battery switch is below the second dial. The jack shown on the left is for the *Loud Speaker;* the one on the right is for the *Telephone Receivers.*

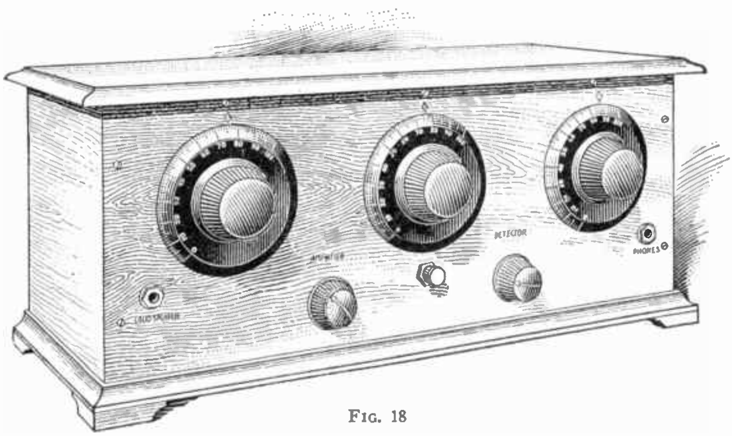


Fig. 18

After the necessary connections have been made, the tuning is started by setting the second and third dials at *10*, and then rotating the first dial slowly between *5* and *15*. If a station is not heard, set the second and third dials each two points higher and again slowly rotate the first dial. Continue this operation until a station is heard, then readjust each dial separately to greatest volume. All three dials will read approximately the same. When the station is tuned in, increase or decrease both the detector and the amplifier rheostats until the desired volume has been attained. In tuning in distant stations, the dials should be rotated very slowly. Make a record of each station tuned. The same stations will usually come in on the same dial readings.

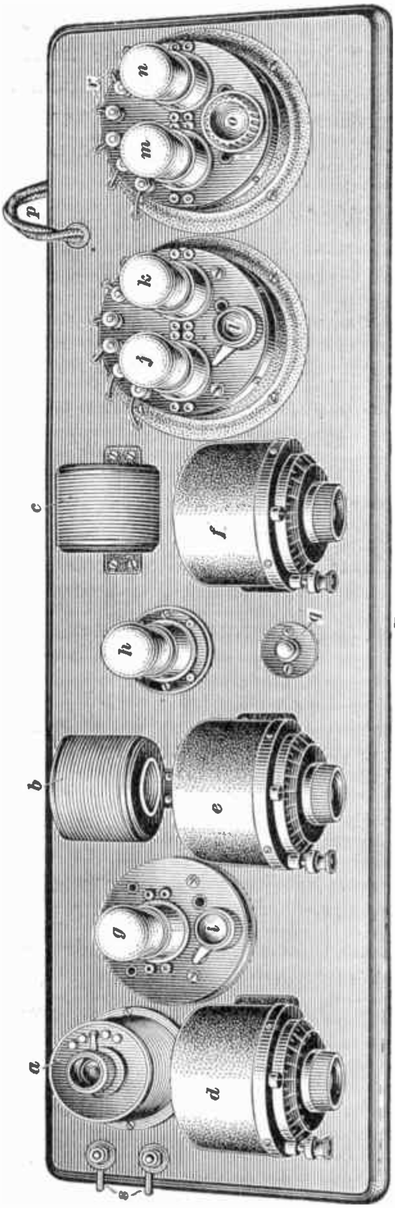


FIG. 19

UV-201-A or C 301-A tubes operate best in a set of this type, in which case, from 22½ to 45 volts should be used on the detector and from 45 to 90 volts on the amplifier. If a soft tube such as the UV-200 is used for the detector, not more than 22½ volts should be applied on the plate. Dry-cell tubes, such as the UV-199 or C 299, may be used advantageously if desired.

ATWATER KENT

59. Construction. Among the several types and styles of set manufactured by the Atwater Kent Manufacturing Company, is found model 12, shown in Fig. 19, which is rather distinctive. It is of the open construction type, with all the apparatus mounted on a baseboard. This set consists of two stages of tuned radio-frequency amplification, a detector, and three stages of audio-frequency amplification. The air-core transformers *a*, *b*, and *c* are tuned by means of the variable condensers *d*, *e*, and *f*. Several taps are taken from the primary of the first radio-frequency transformer *a*, and these are connected to switch points on top of the transformer. A switch arm making contact with the switch points connects the number of turns necessary for a given length of antenna. The relative positions of the transformers should be noted.

The two radio-frequency amplifier tubes *g* and *h* are controlled by the one rheostat shown at *i*. The detector tube *j* and the first audio-frequency amplifier tube *k* have also a rheostat *l*. The second and third audio-frequency amplifier tubes *m* and *n* are automatically regulated and require no rheostat. The switch *o* is used to connect or disconnect the third audio-frequency tube *n*. All the battery connections are made by means of a cable *p*, one end of which is permanently connected to the set, and the other carries terminal lugs, which are connected to the proper battery terminals. The battery circuit may be opened or closed by means of the switch *q*. The telephone receivers and loud speaker are connected to the binding posts *r*, and the antenna and ground to the binding posts *s*. All the wiring and the required fixed condensers are underneath the baseboard.

60. Operation.—The operation is started by closing the battery switch and turning the rheostats until the filaments of the tubes have the proper brightness. With each set is supplied a list of dial settings for the different wave-lengths. The dials on the condensers *d*, *e*, and *f*, Fig. 19, are then turned to the numbers given in the list for the desired station. The settings may vary slightly with different sets, so it is advisable to make slight variations in the tuning if the desired station is not heard on the listed setting. Experience will soon show whether the settings should be higher or lower than those given in the list.

When once a station has been tuned in, it can again be tuned in by turning the dials to the setting. By making a list of the settings for the different stations that were heard, it will be an easy matter later to reach these stations again.

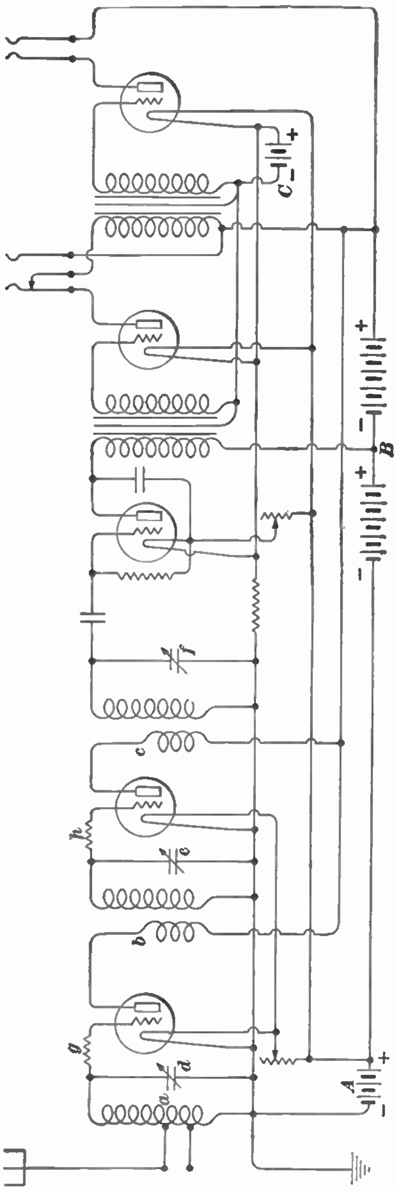


FIG. 20

I L T 450—19

EISEMANN BROADCAST RECEIVER

61. Circuit Diagram and Construction.—The Eisemann Magneto Corporation uses resistances and special air-core transformers in the radio-frequency stages of the five-tube receiving set, shown in Fig. 20. The radio-frequency transformers are made in two sections, as shown at *a*, *b*, and *c*, Fig. 21, which is a rear view of the set. The first of these transformers *a*, Figs. 20 and 21, is in reality an autotransformer with taps taken for long and short aerials. The second and third transformers *b* and *c* have each a primary winding of very few turns, and a secondary winding of a larger number of turns. These transformers are tuned with the condensers *d*, *e*, and *f*. The coils are so constructed that there is very little stray magnetic field, and their positions in the set further reduce the liability of any interaction between them. The resistors *g* and *h*, Fig. 20, each of 550 to 575 ohms, introduce enough resistance to prevent the setting up of oscillations in the

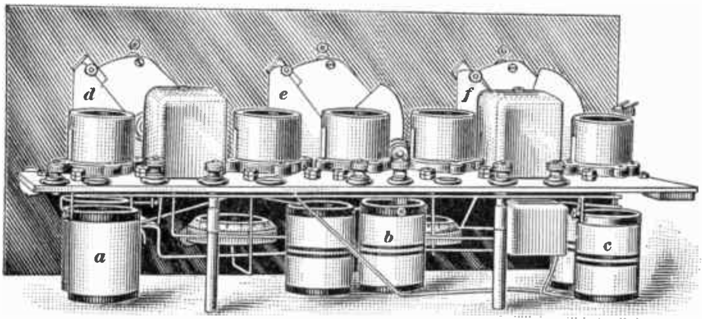


FIG. 21

grid circuits. The detector and audio-frequency amplifier circuits do not differ to any great extent from the other circuits here considered.

62. Operation.—When all the electrical connections have been made, the tuning of the set may be started. Rotate the dials, Fig. 22, keeping all three matched until a signal is heard. It may be necessary to adjust the dial of condenser *d*, Fig. 20,

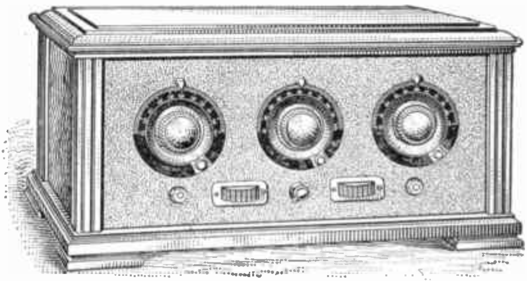


FIG. 22

slightly to compensate for variations in the length of the antenna. However, with an aerial of the average length, it will be found that all three dials have the same reading at all wavelengths.

ZENITH RADIO RECEIVER

CIRCUIT CONNECTIONS

63. The Super Zenith radio receiver manufactured by the Zenith Radio Corporation employs six tubes, preferably of the UV-201-A type, two stages of radio-frequency amplification, detector, and three stages of audio-frequency amplification. The two radio-frequency grid circuits *a* and *b*, Fig. 23, and the detector grid circuit *c* are tuned by variable condensers.

The principle under which this set is designed is that of changing the coupling between the primary and secondary of the radio-frequency transformers with the different condenser settings so as to keep the receiver always in a sensitive but stable condition. This is accomplished by having a portion of the primary winding mounted on the condenser shaft so as to rotate with the condenser. Two of the condensers are belted together so that in operation only two knobs are necessary to operate the three condensers. A small correction vernier condenser is connected across one of the variable condensers so that any slight errors can be corrected when necessary. A switch on the front of the panel allows the choice of two degrees of coupling to the antenna, which is untuned. A resistance control *d* is placed in the plate circuit of the first radio-frequency tube so as to give the operator the necessary volume control. The stage-control switch *e* allows the choice of one, two, or three stages of audio-frequency amplification. On some models a continuously variable resistance serves this purpose.

TUNING

64. The receiver is tuned by the two large knobs *a* and *b*, Fig. 24, which control the three condensers, and the small vernier condenser is controlled by a knob mounted behind the right-hand knob *b*. The rheostat *c* should be turned completely to the right, as individual resistances are employed that allow exactly 5 volts at the filament terminals when the rheostat is

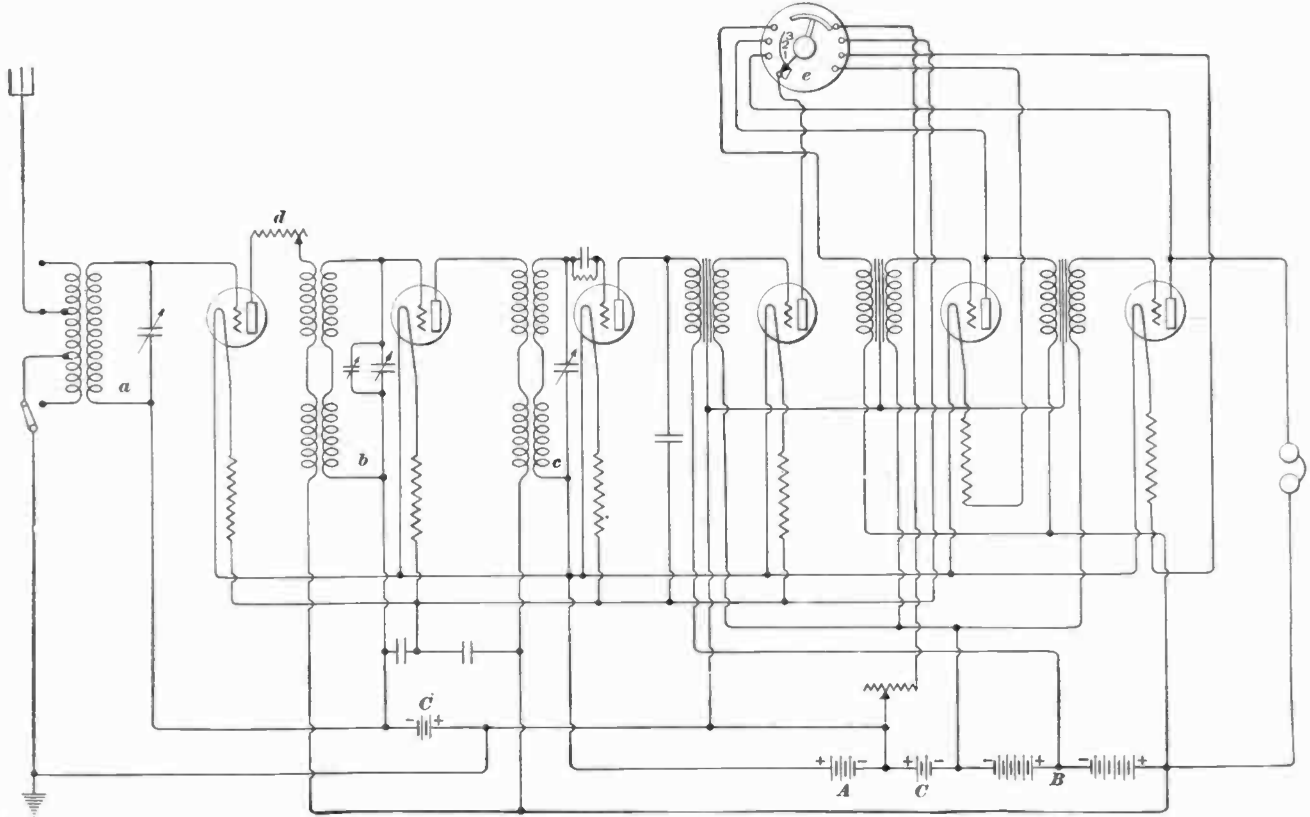


Fig. 23

completely cut out. The rheostat is only used when dry-cell tubes are employed. The stage-control switch *d* should be turned to point *1* for preliminary tuning. The compensator *c* (this being a resistance in the plate circuit) should be turned to the right to a point where good signal strength is obtained but below the point of unstability. The small switch *f* in the lower right-hand corner of the panel, when turned to the left, gives the smallest degree of coupling to the antenna and hence the greatest selectivity. When this switch is turned to the right, less selectivity will be obtained with a considerable increase

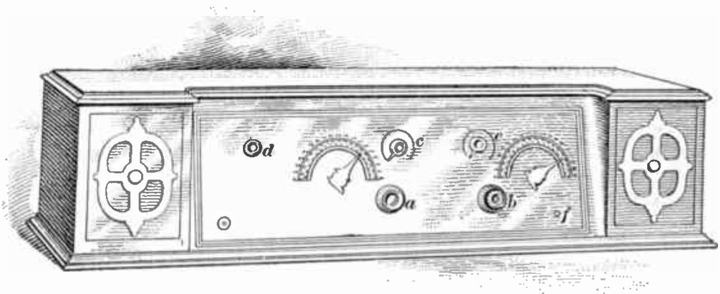


FIG. 24

in signal strength, especially on the higher wave-lengths. For an antenna over 100 feet in length it is desirable to use a series condenser of about .00025 microfarad, or smaller. This is quite important when the set is located in the immediate vicinity of powerful broadcasting stations.

The principal advantage of this receiver over other receivers of a similar type is the fact that the set is automatically maintained in its most sensitive condition over the entire broadcast band, with the added advantage that the set may be controlled at all times under different adjustments. This allows for maximum signal strength with the required selectivity as near as it is possible to obtain these two conditions.

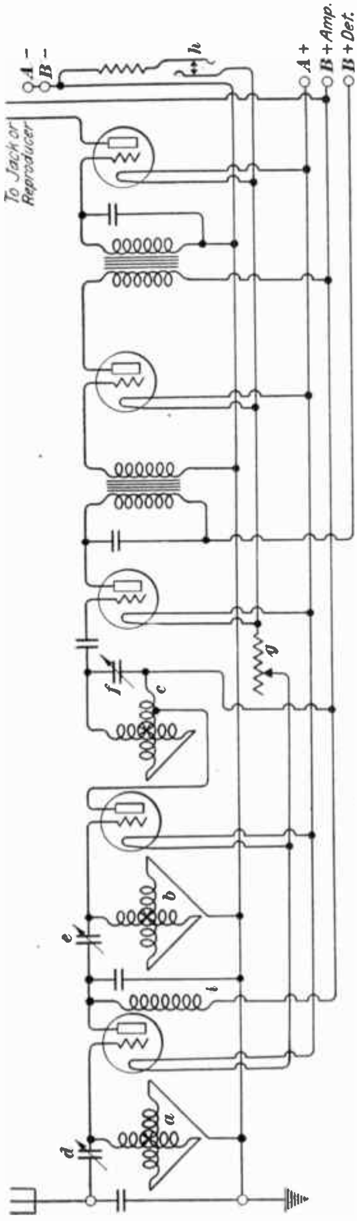


Fig. 25

MAGNAVOX BROADCAST RECEIVER

CIRCUIT DIAGRAM AND CONSTRUCTION

65. A circuit diagram of types TRF-5 and TRF-50 receiving sets of The Magnavox Company is shown in Fig. 25. The front panel and a subpanel with the apparatus mounted in position are shown in Fig. 26. To bear out the relation between the two figures, similar reference letters are used to designate corresponding parts.

The set consists of two stages of radio-frequency amplification, detector, and two stages of audio-frequency amplification. The radio-frequency stages and the grid circuit of the detector tube are coupled and tuned by the variometers *a*, *b*, and *c*. The three variometers are mechanically so connected that one control operates all of them simultaneously. Small discrepancies in the tuning of the three units are corrected by the three small variable condensers *d*, *e*, and *f*. In

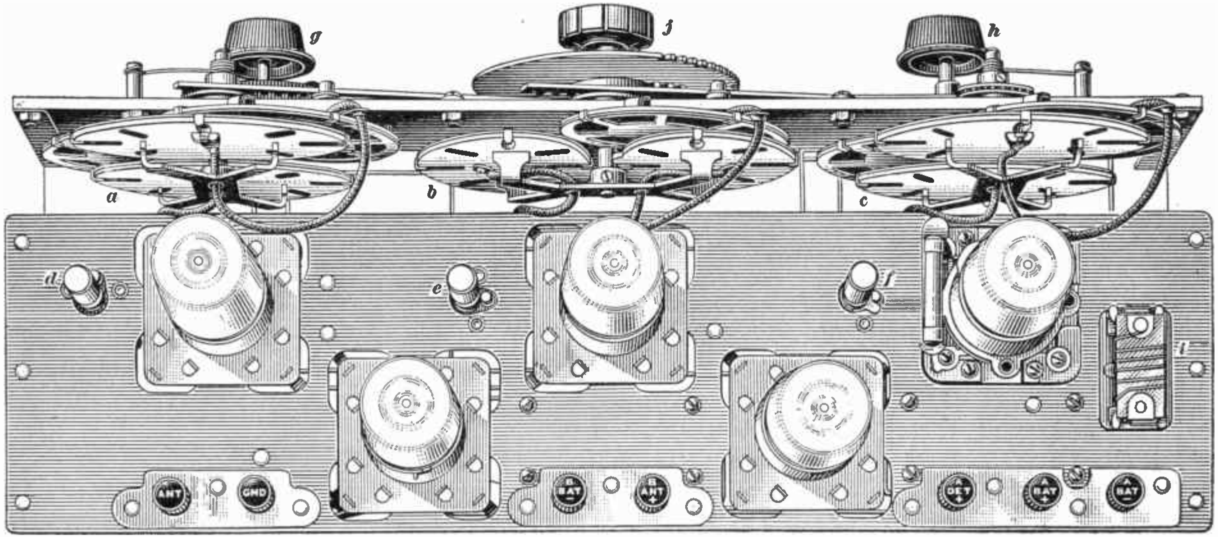


Fig. 26

Fig. 26 only the control knobs of these condensers are shown.

The filament circuits of all the tubes are controlled by the one rheostat *g*; this is called the volume control. The battery switch *h* serves the usual purpose. The plate current of the first radio-frequency tube passes through the choke coil *i*; in the second radio-frequency stage the plate current passes through a small portion of the coupling variometer *c*. The vacuum tubes are of special construction but their operation is practically the same as that of standard tubes.

TUNING

66. Turn the battery switch *h*, Figs. 25 and 26, to *ON*. Turn the volume control *g* clockwise as far as it will go. Do not force it, as the stop is positive. If a howl is set up in the reproducer, turn the volume control *g* back until the howl stops. Move the selector *j*, Fig. 26, a few degrees to the right or left until the station comes in at maximum volume. If a howl is set up turn back the volume control *g*.

On operating the set for the first time it is extremely important that the set is properly tuned. For this purpose there are provided on the tube mounting panel inside the box, three white porcelain knobs that control the condensers, *d*, *e*, and *f*, located below the panel. These are the tuning controls and are used to tune accurately the three variometers to exact resonance. This tuning is of prime importance to the proper working of the set. When this adjustment has been obtained all station selections are made with the single control *j*, which simultaneously tunes the three variometers *a*, *b*, and *c*. The audio-frequency transformers are mounted underneath the sub-panel.

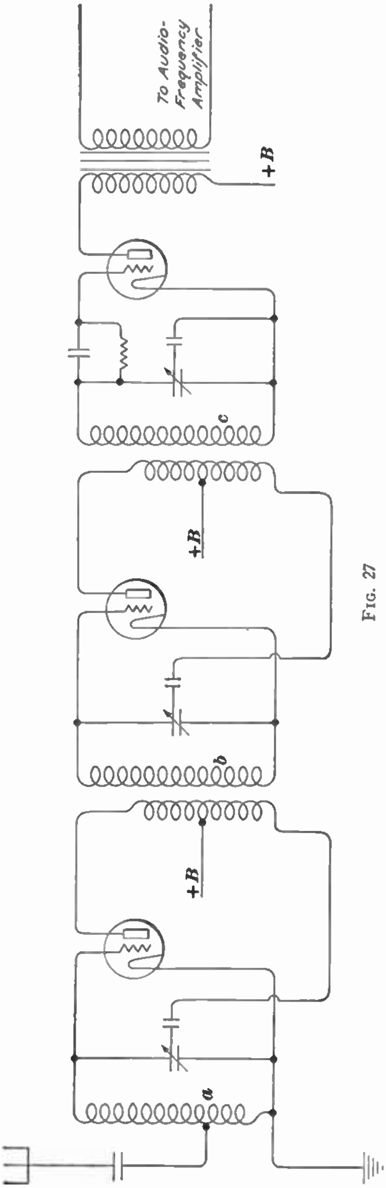


FIG. 27

GREBE SYNCHROPHASE

DISTINCTIVE FEATURES

67. The Grebe Synchrophase, manufactured by A. H. Grebe and Company, Inc., comprises two stages of tuned radio-frequency amplification, detector, and two stages of audio-frequency amplification. The distinctive features are mainly in the radio-frequency amplifier, the circuit diagram of which is shown in Fig. 27. There are three radio-frequency coupling transformers *a*, *b*, and *c*, one *a* between the antenna and the first tube, another *b* between the first and second radio-frequency amplifying tube, and the third *c* between the second tube and the detector. These transformers have a special construction with the windings sectionalized and wound on two parallel cores. This construction tends to reduce the amount of interference and coupling picked up directly by these coils. The detector and audio-frequency amplifier tubes operate as do the corresponding tubes in other sets and a strong output signal is produced.

The selectivity is fully equal to that of the usual set employing two stages of tuned radio-frequency amplification. The receiving range is also comparable with that of other sets in its general class. While the circuit connections are not the same, the set may be said to resemble closely the neutrodyne circuit, at least for all practical purposes. The design of the coupling coils or tuned transformers, and some other features, are, however, original with this particular set. The method of neutralizing is by means of small condensers connected in series with a portion of the primary winding and the tuning condenser.

TUNING

68. The tuning of the Grebe set is accomplished by the condensers connected across the radio-frequency transformers. The condenser dials are shown at the upper portion of Fig. 28. The settings of these three dials are approximately the same,

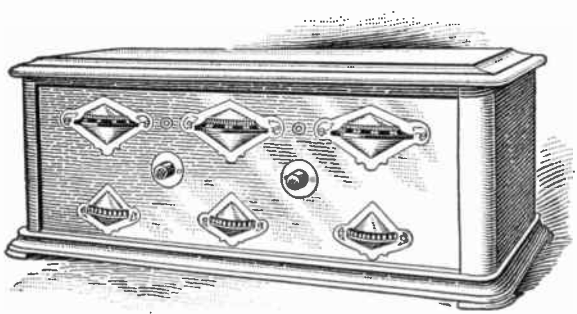


FIG. 28

and the tuning is quite critical or sharp. A special design of the plates causes the lower wave-length stations to be as well separated on the condenser scales as are the higher wave-lengths. By noting the dial settings it is possible to retune to that same wave-length at any subsequent time. After the desired station is tuned in, the volume control may be regulated to give the desired loudness of signals. Naturally this adjustment will depend upon the limitations of the set but ample volume may be obtained on even distant stations. Manipulation of the filament rheostat will give considerable control of the operation and volume, and this adjustment may be a very critical one on distant stations.

The Grebe Synchrophase is designed particularly for UV 201-A and C 301-A types of tubes, and these will require a storage battery for filament-current supply. The set may be operated with dry-cell types of tubes also, but with less volume than would be obtainable from the other tubes. The Company also makes a battery box or compartment that matches the cabinet, and which forms a sort of base for the main cabinet. This makes a very convenient way to conceal the batteries.

FADA NEUTRORECEIVER

CONSTRUCTION OF SET

69. The Fada Neutroreceiver is a five-tube neutrodyne receiving set manufactured by F. A. D. Andrea, Inc. The arrangement of the parts of this set is shown in Fig. 29. Except for the insertion of neutralizing condensers the circuit connections are fundamentally the same as in any other tuned radio-frequency amplifier set. The neutralizing condensers when properly adjusted add to the stability of the set.

The three radio-frequency transformers *a*, *b*, and *c* are tuned by their respective condensers. The condensers are fastened to the panel behind metallic shields. These shields are connected to the supporting frame and both the frame and the shields are grounded. This shielding reduces body capacity to a large extent and thus aids in the tuning of the set. Only one of the neutralizing condensers is seen in the figure as indicated at *d*; the other is practically concealed by the audio-frequency transformer *e*. One of the neutralizing condensers is connected between the secondary winding of the transformer *b* and the grid of the first radio-frequency amplifier tube; the other is connected to the secondary of transformer *c* and the grid of the second radio-frequency amplifier tube. Two stages of audio-frequency amplification are provided and these are coupled by means of the transformers *e* and *f*.

70. The filament current to the two radio-frequency amplifier tubes is controlled by the rheostat *g*, Fig. 29. The detector and audio-frequency tubes are regulated by the rheostat *h*. The rheostat *g* controls the quality, and rheostat *h* the volume, of the received signals. Between the two rheostats is

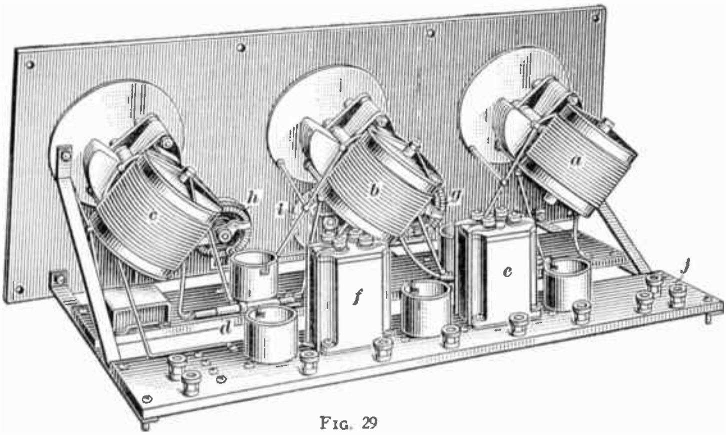


FIG. 29

the selector switch *i*. This switch has three positions. In its first position, the switch opens the battery circuits; in its second position, it closes the battery circuits and connects the telephone receivers or loud speakers to the first stage of audio-frequency amplification; in its third position it switches the telephones or loud speaker to the second audio-frequency stage.

The antenna, ground, battery, and loud speaker binding posts are mounted on the subpanel *j*. The connecting wires are brought to these posts through holes in the rear of the cabinet.

BALANCING AND TUNING

71. The neutralizing condensers in a neutrodyne set must be properly adjusted or balanced before any satisfactory results can be obtained from the set. For balancing purposes a local oscillator or the energy from a nearby transmitting set may be used. With all the circuits closed and the filaments at the proper temperature, rotate the dials on the front panel until a signal is heard, either from the local oscillator or from a broadcasting station. Then remove the first radio-frequency tube and readjust dials until signals come in loudest. Place a small piece of paper on the positive filament

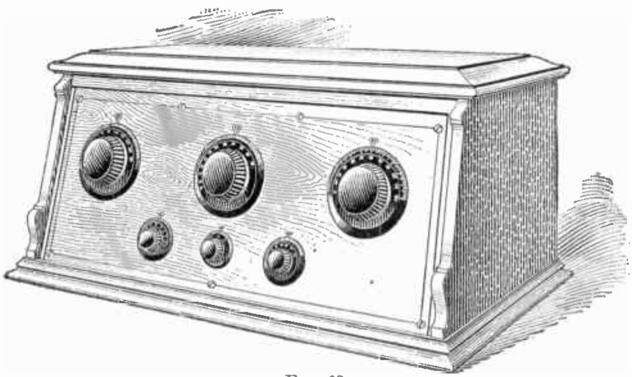


FIG. 30

contact in the socket and insert the first tube, thus opening its filament circuit; the other contacts should be free to touch the pins on the tube. If the signal is heard, adjust the neutralizing condenser until the signal is reduced to a minimum. Do not operate the dials on the panel. Remove the first tube and also the insulating piece of paper. The signals will come much louder with the first tube removed. Insert the first tube in its socket without the insulating paper and remove the second tube, repeating on it the operations that were performed with the first tube. When both tubes have been properly neutralized no further adjustments will be necessary unless the tubes are changed and then only if the new tubes have different characteristics. Some neutralizing condensers have three terminals. If the end terminals do not give complete neutralization, the center terminal may be substituted for one of the end terminals.

72. The Fada Neutroreceiver is tuned with the three large dials shown on the front panel, Fig. 30. These are rotated until the signal comes in clearly. A log may be kept of the dial settings to enable the operator to tune in a certain station more easily, once this station has been received. The *quality* and *volume* dials may be used to suit the requirements of the operator. The smaller center dial operates the selector switch.

CROSLEY TRIRDYN

CONSTRUCTION AND CONNECTIONS

73. The application of radio-frequency amplification, regeneration, and reflex operation is exemplified in the Crosley Trirdyn receiving set, manufactured by The Crosley Radio Corporation. The circuit diagram of this set is shown in Fig. 31, and the internal construction in Fig. 32. Corresponding parts have the same reference letters in both figures.

The antenna transformer *a* is tuned by means of the variable condenser *b*. The primary coil of the transformer has two antenna connections, one for short antennas and the other for longer antennas. The received energy is delivered to the grid circuit of the first tube *c*, where it is amplified at radio frequency and passed through the transformer *d* to the detector tube *e*. The transformer *d* is tuned with the condenser *f*. The grid-condenser and grid-leak combination *g* aid in the detection of the signal. (No grid leak is shown in Fig. 32.)

A connection from the plate of the detector tube *e* leads to the tickler coil *h*, and from the tickler coil to the primary of the audio-frequency transformer *i* and to the *B* battery. Some energy is transferred from the tickler coil *h* to the trans-

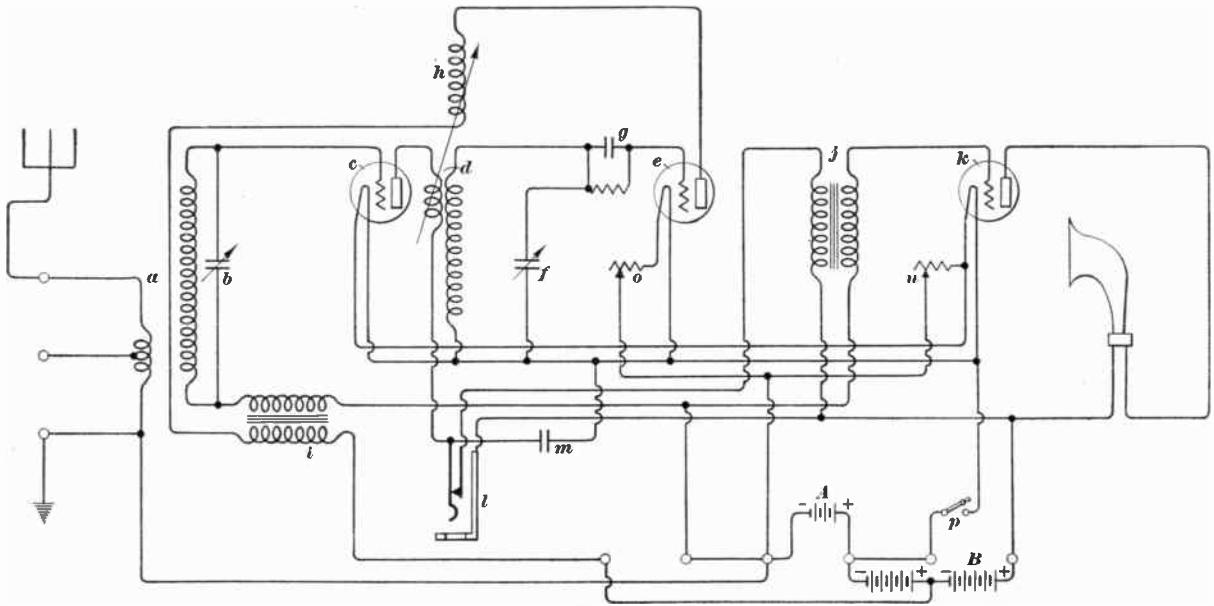


FIG. 31

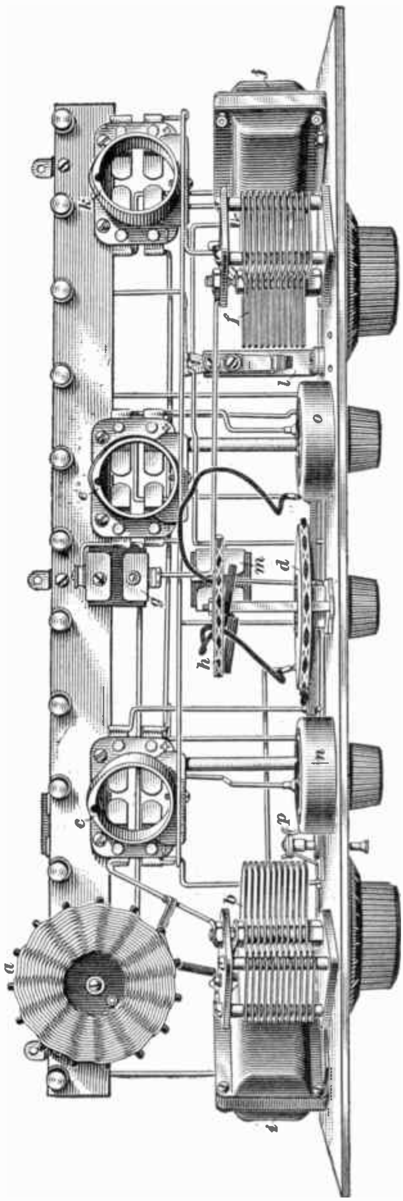


FIG. 32

former *d*, producing regeneration. The transformer *i* has its secondary winding in the grid circuit of the first amplifier tube, hence the signal is amplified at audio-frequency by tube *c* and passed on through the transformer *j* to the amplifier tube *k*. The output from the tube *c* may be taken through the jack *l*. A loud speaker may be connected in the plate circuit of the tube *k*. A by-pass condenser is connected at *m*. One rheostat *n* is used to regulate the filament current of both amplifier tubes. A separate rheostat *o* is used for the detector tube. A battery switch *p* is provided to open the filament circuit when the set is not in use.

OPERATION

74. When the antenna, ground, battery, and loud-speaker connections have all been made, the set is ready for tuning. The battery switch, Fig. 33, is pulled out, and both rheostats turned clockwise until the tubes show the proper glow. The rheostat knobs have the small arrows across them. The condenser dials are then rotated until some station is located. The approach of a broadcasting-station signal will be indicated by a squealing or whistling sound. The condenser dial on the right must be

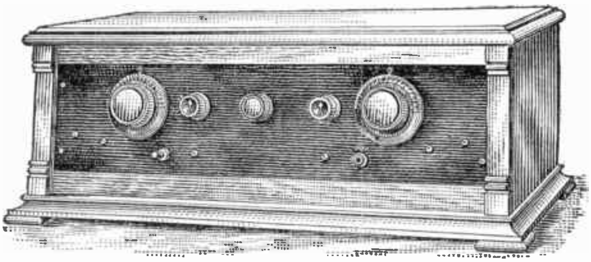


FIG. 33

tuned more carefully than the one on the left. To clear up a signal, adjust the tickler knob in the center of the panel by pulling out or pushing in until the signal is loud and clear. It may then be necessary to readjust slightly the condenser dials.

DE FOREST D-17 RADIOPHONE

THEORY

75. The De Forest D-17 radiophone, manufactured by De Forest Radio Company, is a five-tube radio receiving set with three stages of radio-frequency amplification, vacuum-tube detector, and two stages of audio-frequency amplification. The last radio-frequency tube serves also as an audio-frequency amplifier. The circuit diagram of this set is shown in Fig. 34. Ordinarily a loop antenna is used. A plug connection from the loop is inserted into the jack *a*. If an external antenna and ground are to be used, they are connected to the antenna and ground binding posts in the set. The loop must be used even with an external antenna. The ground is connected to its binding post in the usual way. To

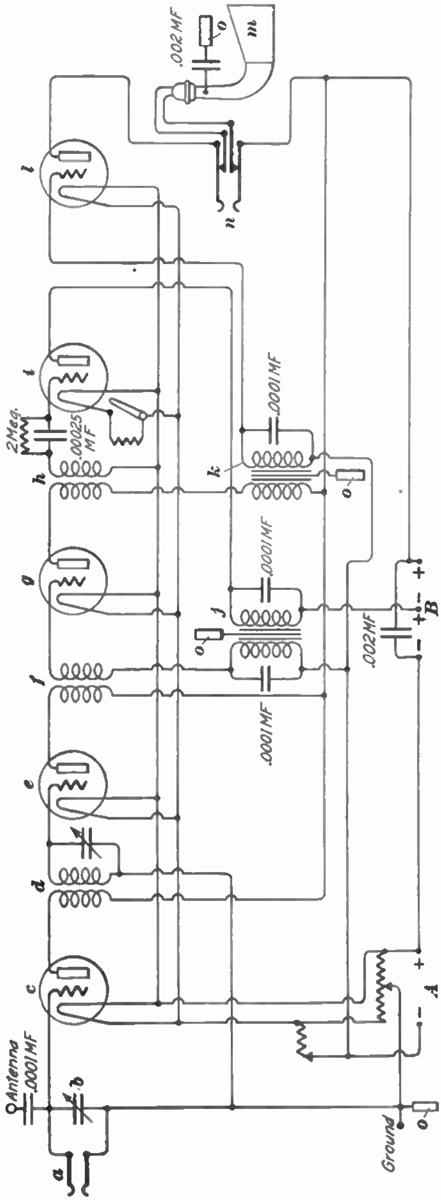


FIG. 34

the antenna binding post is connected a piece of insulated wire about 3 feet in length. The free end of this wire is twisted around the antenna lead-in wire without removing the insulation. There should be no metallic contact between the two wires. The circuit is then tuned by means of the condenser *b*. The signal is amplified at radio frequency by the tube *c*, and passed on to the tuned radio-frequency transformer *d*, tube *e*, transformer *f*, tube *g*, transformer *h*, and the detector tube *i*. The energy from the plate circuit of the detector tube *i* is conducted to the grid circuit of the tube *g*, through the transformer *j*, where it is amplified at audio frequency and passed through another audio-frequency transformer *k* to the tube *l*. The output of the tube *l* is utilized to operate the loud speaker *m*. or the telephone receivers that may be connected through the jack *n*. The shield of transformer *d*. the coils of transformers *j* and *k*, and the frame of *m* are grounded at the shield *o*.

OPERATION

76. The De Forest D-17 radiophone is a complete unit including a loop antenna, the complete set, loud speaker, and the necessary batteries. It is shown complete in Fig. 35. The loop is placed in its jack through an opening in the top of the set. The loud speaker is built in with the output end directly under the panel. On the left and right of the panel are the compartments for the *A* and *B* batteries.

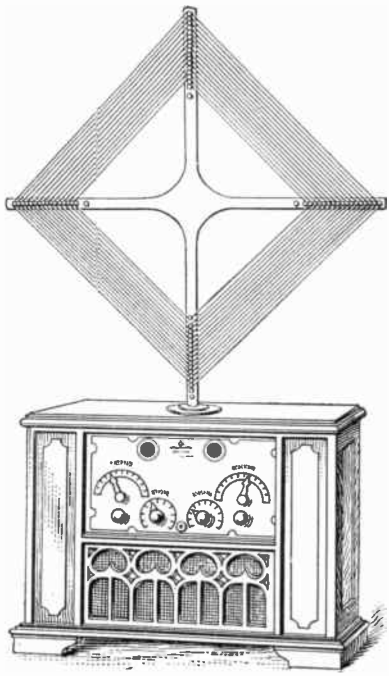


Fig. 35

The two dials on the extreme right and left of the panel belong to the variable condensers and are used in tuning the set. The one on the right is marked *Receiver Tuning* and the one on the left *Amplifier Tuning*. The *Filament* dial operates a rheostat, and the *Sensitivity* dial. a potentiometer. The telephone jack is located below the two smaller dials.

The first step in the operation of the set is to turn the filament rheostat to a point that will give the tubes the required brightness. The potentiometer pointer is placed in about the center of the scale. The two condenser dials are then rotated until a station is found. The potentiometer pointer is then adjusted until best results are obtained. The loop must also be turned in a direction that gives the loudest signal for a given station.

RADIOLAS

RADIOLA III-A

77. Principle of Operation.—*Radiola* is the name used by the Radio Corporation of America to designate its receiving sets. Radiola III-A is one of the several types distributed by this company, and is especially designed for broadcast reception. It uses four WD-11 Radiotrons, one of which operates as a detector and the remaining three as audio-frequency amplifiers.

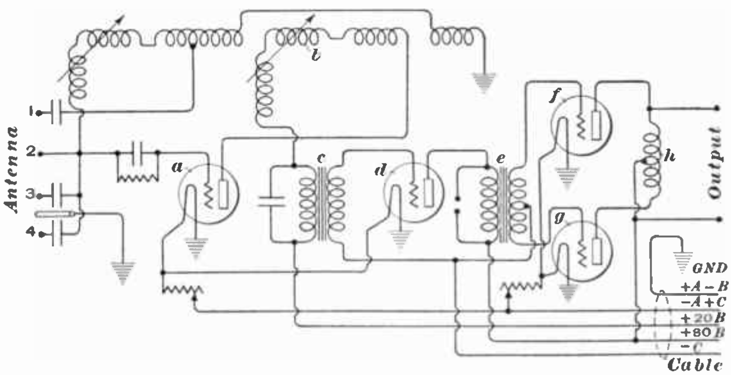


Fig. 36

A circuit diagram of Radiola III-A is shown in Fig. 36. The antenna circuit has a number of coils and condensers arranged in a manner to obtain selectivity and volume, and, at the same time, suppress radiation. Four terminals or binding posts are provided for connection to the antenna, this giving six different available circuit arrangements, which are as follows:

No. 1.—Antenna on terminal *4*, link between *3* and *4* open. This is a single-circuit connection that, on an average antenna, will cover the approximate wave-length range of 200 to 360 meters, corresponding to a frequency range of 1,500 to 830 kilocycles.

No. 2.—Antenna on *3*, link open. This is a single-circuit connection that, on an average antenna, will cover the approximate wave-length range of 250 to 480 meters, corresponding to a frequency of 1,200 to 625 kilocycles.

No. 3.—Antenna on *2*, link open. This is a single-circuit connection that, on an average antenna, will cover the approximate wave-length range of 315 to 560 meters, corresponding to a frequency range of 950 to 535 kilocycles.

No. 4.—Antenna on *2*, link on *3*. This is a closed single-circuit connection that, on a very small antenna, such as an indoor one, will cover the approximate wave-length range of 270 to 575 meters, corresponding to a frequency range of 1,070 to 520 kilocycles.

No. 5.—Antenna on *1*, link on *4*. This is a selective single-circuit connection that, on an average antenna, will cover the approximate wave-length range of 195 to 375 meters, corresponding to a frequency range of 1,540 to 800 kilocycles.

No. 6.—Antenna on *1*, link on *3*. This is a selective single-circuit connection, that on an average antenna, will cover the approximate wave-length range of 310 to 640 meters, corresponding to a frequency range of 970 to 470 kilocycles.

The coils shown in a horizontal position, Fig. 36, are stationary; the vertical coils are the rotors. This gives a variometer or vario-coupler effect, either of which is utilized in tuning the antenna and feed-back circuits. The tube *a* acts as a detector. The plate current passes through the adjustable tickler coil *b*, the primary winding of transformer *c* to *+20 B* battery. The signal is amplified at audio-frequency by the tube *d* and passed on to the push-pull amplifier consisting of the special transformer *e*, the tubes *f* and *g*, and the special output transformer *h*.

The battery and ground leads are formed into a cable, each lead having different colored insulation. A set of terminals is provided in the plate circuit of the first amplifier tube *d* for listening to signals with telephone receivers only.

78. Finding Signals.—With the ground and battery connections properly made. select a suitable antenna connection, Fig. 37, according to one of the combinations just considered. If a loud speaker is to be used, push its cord terminals into the pin jacks on either side of the word *Output* at the left of the panel. Then turn both rheostat knobs to the right until the filaments of all four radiotrons glow at a dull-red color. If a headset is to be used instead, push its cord terminals into the pin jack just above the words *1st stage* near the front of the panel, and then turn only the rheostat near the middle of the panel until the filaments of the two radiotrons at the right glow at a dull-red color. The pin jack at

FIG. 37

the left is positive. The cord tip on the lead with the colored tracer thread should be inserted in this jack. The other rheostat should be left on the *Off* position, unless the loud speaker is used. Then set the *Amplification* at about *3*. Turn the *Station Selector* slowly back and forth over the scale. If signals are heard, carefully adjust the *Station Selector* until the signals become loudest and then turn the tickler coil, marked *Amplification* to the right, when the signals should become still louder. Do not turn *Amplification* to the point where the signals become distorted or where whistles and howls are produced. If no signals are heard the first time, turn *Amplification* one-half division to the right and try again. If the first antenna combination fails, try another.

RADIOLA SUPER VIII

79. The Radiola Super VIII is a name and type number applied to one type of superheterodyne set made by the Radio Corporation of America. It represents one of the most sensitive types of radio receiving circuits. One of the main drawbacks to the use of superheterodyne sets was the large number of tubes required to operate them. With the advent of tubes requiring very small amounts of filament current this objection has been largely removed. The superheterodyne, being so sensitive, may be operated with a loop antenna.

The Radiola Super VIII, shown in Fig. 38, is an entirely self-contained unit. The loop antenna is concealed in the lower part of the large cabinet *a*. The upper part *b* of the top section is given over to an opening of a built-in loud speaker. The lower portion *c* of the top section forms the panel for the radio receiving set proper. All tuning is done from this panel and the loop antenna is also controlled by a control knob *d* on this panel. A shelf *e* folds up and conceals the tuning and operating controls when it is so desired. Compartments are provided in the back of the cabinet for all the batteries used in the operation of the set.

This set is particularly adapted for use in locations where it is not practical to erect an outdoor antenna, and where an extreme degree of selectivity is desirable. Although not a portable set, it may be moved to any location in the room, or even into another room with no effect on its operation. With the artistic design of the complete cabinet, it may be considered a piece of furniture both as regards its appearance and usefulness. It is designed to give reception of distant stations or local ones at will and to operate with a minimum number of controls.

80. The original type of superheterodyne required eight tubes for normal operation. By the use of a special circuit in the Radiola Super VIII, as shown in Fig. 39, one tube acts both as a preliminary detector and radio-frequency oscillator. This oscillator works at a comparatively low frequency, and a harmonic is used to form the beat frequency. This gives rise to the proper full name of this type, which is *second-harmonic superheterodyne*. With careful design of the coupling transformers and of all features that enter into the

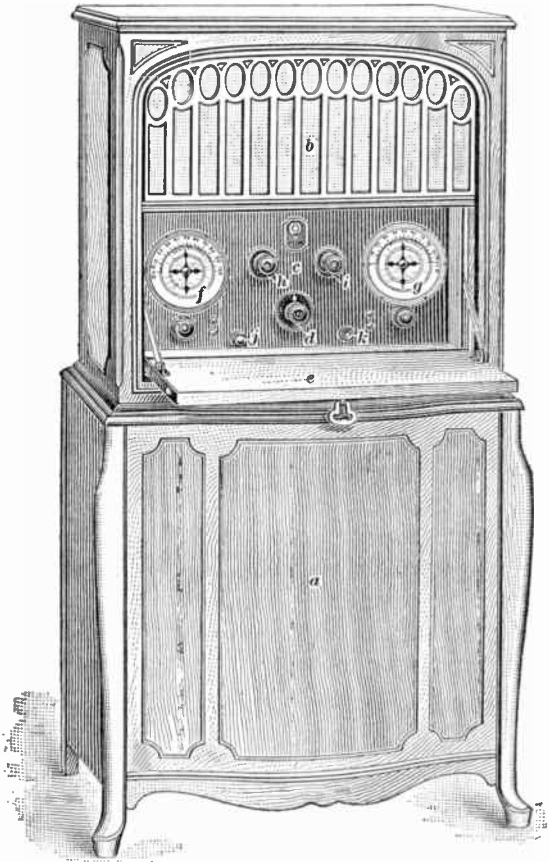


FIG. 38

assembly, this set is able to give results comparable with those obtainable from eight- or nine-tube sets.

The path of the signal through the set is an interesting one. The loop antenna *a* picks up the signal to which it is tuned by a shunt variable condenser *b* (dial *f*, Fig. 38). The signal

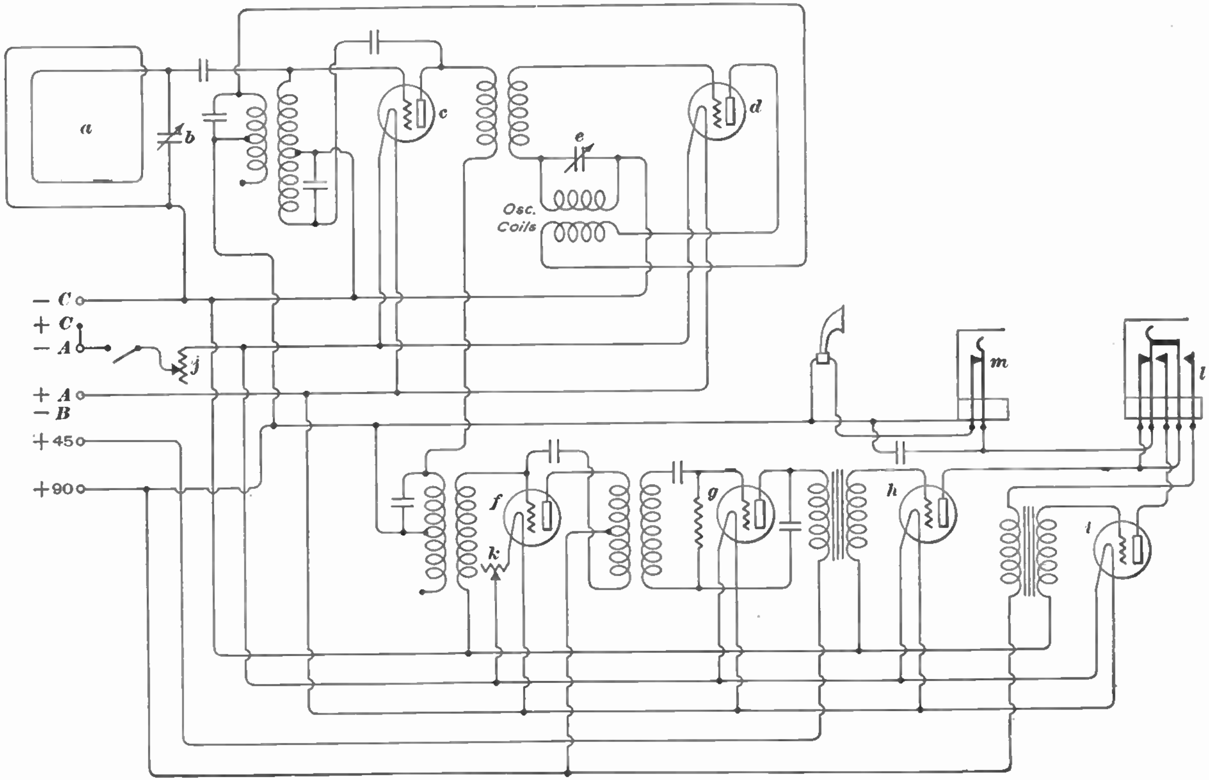


Fig. 39

then goes through the first tube *c*. This tube amplifies the signal at radio frequency, just as it is received or picked up. The next tube *d* has two functions to perform and has a special circuit, which is double so far as results are concerned. The circuit is tuned to a frequency, the second harmonic of which beats with the incoming signal, by a variable condenser *e* (dial *g*, Fig. 38). These two condensers *b* and *e* are the actual tuning devices in the set, which makes it convenient to tune with two hands. The circuits of this second tube *d* are so arranged that the higher-frequency component is eliminated, and the resultant beat frequency, called the intermediate frequency, is delivered to the next tube.

The signal, now carried by an intermediate-frequency wave, is reflexed or sent back through the first tube *c* for additional amplification. The first tube *c* thus performs two simultaneous duties. The signal next passes through the third tube *f*, which amplifies it still further at the intermediate frequency. The fourth tube *g* acts as a second or final detector and changes the signal to an audio frequency. The fifth and sixth tubes *h* and *i* are the usual audio-frequency amplifiers. The input or first tube *c*, which operates as a radio-frequency amplifier on the incoming signal, blocks any oscillations in the set, and makes it non-radiating.

81. All the filaments of the Radiola Super VIII are connected in parallel and their current or operating temperature is controlled by a rheostat *j*, Fig. 39 (*h*, Fig. 38). An auxiliary high-resistance rheostat *k* (*i*, Fig. 38) provides an additional control on the filament current of the intermediate-frequency amplifier tube *f*. With the resistance of this rheostat all out, the tube receives the same filament voltage as do all the others. As the resistance is increased the filament voltage and current decrease, and the amplification provided by the tube is diminished. This rheostat provides a convenient method for controlling the volume of the output signal and is known as a volume control. A push-pull switch *l* (*j*, Fig. 38) serves to remove or connect the last audio-frequency tube with the circuit. This is chiefly for use in head-phone reception and removes the extra noises that may be present in the second audio stage. It could be employed to decrease the volume with a loud speaker, but the filament current control is far better in practice. Head telephone receivers or a separate loud speaker may be connected in the output circuit by plugging in to the telephone jack *m* (*k*, Fig. 38).

In order to secure maximum amplification, the transformers and other parts of the operating circuit are very carefully designed and assembled. The whole assembly, so far as is possible, is sealed in a wax compound, which protects it from moisture and also holds all parts firmly in place. This also prevents the coils from moving so as to produce undesirable coupling effects and makes a compact assembly uniformly possible. All the tubes are mounted in a special socket assembly with all in one row. A spring suspension keeps table and other jars from reaching the tubes, which jars might cause audible or microphonic vibrations that would be audible in the loud speaker.

82. The Radiola Super VIII, Fig. 38, makes a very complete well-appearing set, as everything necessary to operation is contained in the one cabinet. Although the cabinet is large, it is so designed and proportioned as to present an attractive appearance. When the desk-shelf is up, it covers the operating panel and control knobs and hardly looks like a radio receiving set. A special loud speaker of unusual design and construction is built-in and has an opening just behind the grill work in the extreme top section of the cabinet. The various battery compartments are accessible and all battery connections are made from the rear of the cabinet. The *A*, *B*, and *C* batteries are all dry cells made up in conventional-type units.

This set is quite easy to tune and operate. In tuning, the desk-shelf *e* is lowered and the rheostat *h* set so as to produce some noise from the set. Then the two tuning dials *f* and *g* are varied almost simultaneously, or one may be moved in steps and the other turned back and forth over a small part of its range until the desired station is received. It will probably be necessary to diminish the filament current to some extent, and to try readjusting the tuning controls by small amounts until best final results are secured. The volume control *i* is then regulated to give the desired output signal strength. Since the receiving circuit and tuning are absolutely constant, it is feasible and advantageous to record the dial settings at which certain stations are received. Paper dials may be attached to the panel and the various station call letters indicated directly thereon, for convenience in retuning to those stations.

The selectivity of the Radiola VIII is all that could be desired. Naturally, selectivity is improved by the loop antenna, which may be turned at right angles with a local interfering station to eliminate it entirely. The loop antenna and set are so well-proportioned that quite distant stations may be received consistently, and remote stations under reasonably good conditions. The output signal strength should be ample to operate the loud speaker, even on the distant stations.

83. The Radiola Superheterodyne is a semiportable set employing the same tuning element as just described. It is put up in a compact cabinet with a small fixed loop antenna and with battery compartments in the ends. A handle on the top may be used to move the set, or to turn it so as to receive stronger signals with the loop pointed toward the broadcasting station. The front panel is practically the same as that illustrated for the Radiola Super VIII.

The Radiola Superheterodyne has a telephone jack for the connection of a loud speaker or telephone receivers. The same type of tube is used here and also the same complement of batteries. Owing to the smaller loop the range and signal strength is somewhat less with the Radiola Superheterodyne than with the Radiola Super VIII. If a loop of the same size as that in the Radiola Super VIII is connected with the Radiola Superheterodyne an equal signal strength should be obtainable. However, the signal strength is sufficient for ordinary local and moderately distant stations with the coil antenna installed in the set. Sometimes it is necessary to turn the set so as to make it directional to receive or eliminate the signals from a particular station.

BRIEF SURVEY OF OTHER TYPES

84. There are many other types of receiving sets developed by the Radio Corporation of America. Among the more popular types may be mentioned Radiola 20, Radiola 25, Radiola 26, Radiola 28, and Radiola 30.

Radiola 20 is a five-tube balanced radio-frequency receiver equipped with controllable regeneration. An important feature of this set is the one-control method of tuning, the tuning condensers for all three radio-frequency circuits being mounted on one vertical drum control dial. Provision is made to adapt the set to aerials of different lengths.

Radiola 25 is a second-harmonic six-tube superheterodyne. In appearance it resembles Radiola 20, having a sloping panel and a similar one-control tuning mechanism. A loop for intercepting radio signals is mounted directly on top of the case.

Radiola 26 is a complete and self-contained portable six-tube superheterodyne. All the necessary parts, including the loop, batteries, and loud speaker are within the one case. The loop is pivoted within and forms part of a hinged cover. When the cover is swung out, the loop within the cover may be turned in any desired direction. The set may be used for broadcast reception the same as any other Radiola. Its sensitiveness, compactness, and directional features make it especially adaptable for locating sources of interference.

Radiola 28 is a desk-model eight-tube superheterodyne. In appearance it resembles Radiola 25, having a similar cabinet, loop, and one-control condenser drum.

Radiola 30 is an eight-tube superheterodyne, with all the parts built-in in an artistic cabinet. Complete operation of this receiver is obtainable from the 60-cycle 110-volt lighting circuit of the home, eliminating all batteries and every suggestion of a technical instrument.

SELECTION OF SET

85. It is just as hard to recommend the type of radio receiving set that any one should buy as it is to advise one as to the type of automobile or house he would like. Some sets are designed principally to furnish a really first-class circuit for radio reception; others are designed more to provide a pleasing appearance. However, much must be said for the manufacturers who attempt, and often succeed, in putting a really good set in a cabinet of artistic design.

The inherent properties of various circuits make differences that cause some sets to appeal to some persons, whereas other people are attracted by still other features. A multiplicity of tuning controls always holds a certain amount of fascination not possessed by one or two controls on a set. If the multi-control set possesses features of selectivity or other desirable properties, that is another matter; but two-control sets can be made nearly as sensitive as one would care to go in a radio set. This is exclusive of the filament-current supply control, which is often reduced to one rheostat. Three tuning controls seems to be about the limit for practical purposes, and these are not so difficult if they may be calibrated and stations picked up by simply resetting to those positions. The tendency seems to be toward two tuning controls or one tuning control and one volume control.

86. Where electric service is available, apparatus may be used to supply the filament and plate-circuit energy directly therefrom. This usually includes a transformer and rectifier system for alternating current or a resistance unit for direct current with a filter to eliminate any supply line noises. Such a device will eliminate the *A* and *B* batteries, which are a considerable source of expense and trouble. In other cases only the plate-voltage supply is from the power line. This supply of filament and plate-circuit energy from the power-line supply tends to make the radio set more self-contained and much more convenient. The *C* or grid bias battery does not discharge very rapidly, so needs replacing only infrequently.

Sometimes the grid bias is also secured from the power line supply device.

Some of the most popular radio sets use an outdoor antenna system, although most of them will operate after a fashion with only an indoor aerial. Other types of sets are designed solely for operation with the relatively weak signal picked up by a loop antenna, often built into a set.

RADIO-TELEGRAPH TRANSMITTERS

DAMPED-WAVE COMMERCIAL TRANSMITTERS

ROTARY AND QUENCHED GAPS

ROTARY GAP

1. Introduction.—The early types of spark transmitting systems have been greatly improved and simplified with the result that now may be found only two general systems which are used to any great extent commercially for damped-wave, or spark, radio-telegraph communication purposes. These are commonly termed the *rotary-gap type*, and the *quenched-gap type*.

2. Synchronous Gap.—The disk discharger, or rotary gap, has many advantages over the early spark transmitters of the open-gap type; namely, it provides regular sparking without missing, thus giving a pure musical note; it eliminates danger of arcing if the voltage rises too high; it gives automatic prevention of the return of energy from the aerial circuit to the primary circuit, allowing closer coupling than with an ordinary spark set; this means more energy delivered to the aerial and a more efficient transmitter.

Rotary gaps of the size used with the average 2-kilowatt, or 2,000-watt, ship spark sets are enclosed in an iron casing *a*, Fig. 1, which acts as a silencer to the spark. This casing is fitted with an inspection door and glass window and is provided with a fan arrangement that circulates the air inside the casing, driving off the nitrous gases through outlets in the casing fitted with sound-proof material. If the rotary gap is so arranged that two of the rotary studs on the disk *b* are opposite the two fixed studs *c* and *d* at the instant of maximum voltage across the condenser so that a maximum of oscillating energy may discharge across the gap, the gap is then termed the *synchronous rotary gap*. This implies that there is one spark for each half cycle of generator voltage, so that the sparking rate

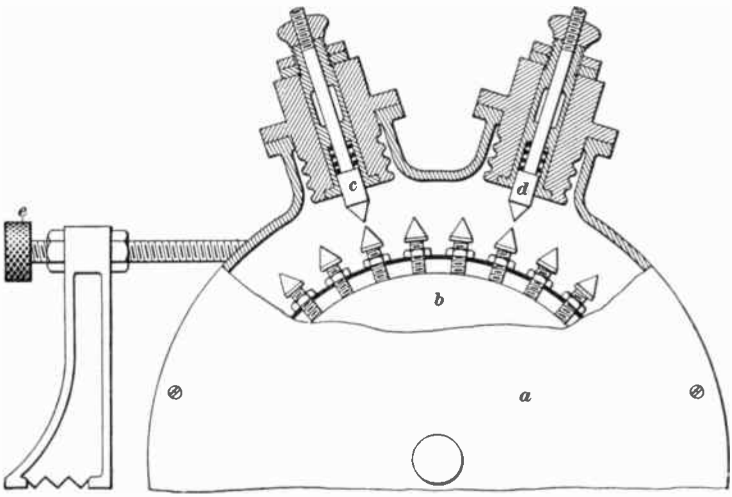


FIG. 1

equals twice the generator frequency. The rotary disk has as many studs as there are poles on the generator and is driven at the same speed as the generator.

The wedge-shaped studs on the disk *b* move past the stationary electrodes *c* and *d*. The clearance between the studs and the electrodes usually does not exceed .01 inch. Two of the studs on the disk *b* should be opposite the stationary electrodes when the voltage across the latter is maximum. If this condition does not obtain, the casing with the stationary electrodes may be shifted slightly by means of the adjusting screw *e* until a position is found where the discharge takes place at the proper time.

3. Non-Synchronous Gap.—Now, if there are more studs on the rotary disk than poles on the generator, a discharge can be obtained before the half cycle is complete; the condenser will charge up again during the completion of the cycle and a second discharge may be obtained during the half cycle. This is the principle of the *non-synchronous* or *asynchronous rotary-gap* system. The condenser in this system never charges up to the maximum voltage and therefore the oscillating energy at each discharge will be less than with the synchronous method and the gap will have to be smaller. Although there is less energy at each discharge, there are more discharges per second and the ultimate oscillating energy per second may be the same with the added advantage of a higher spark note. The sparking note is given by the following expression:

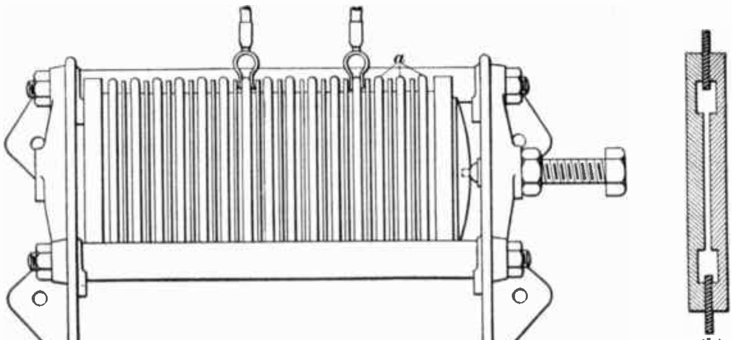
$$\frac{\text{revolutions per minute of disk} \times \text{number of studs}}{60}$$

As there is not necessarily the same amount of energy in each discharge some of the movable studs may regularly get the heavier sparks and wear away faster than the others. This is obviated in practice by putting the fixed electrodes on the supporting ring at a different distance apart from that of the fixed electrodes arranged for synchronous sparking, thus insuring that every stud will get a heavy and a light discharge alternately and the wear on the studs will be equal.

QUENCHED GAP

4. With the quenched-spark system it was found possible to increase the transmitting range nearly three times over that previously possible with the older systems using the same amount of power input to the set. The spark thus produced has a musical pitch of about 500 cycles ordinarily and is very effective in being distinguished above the usual static noise and interference of other stations. The important feature in the quenched-spark system is in the spark gap, which is of novel design. It is a well-known fact that in order to radiate the most energy from any spark set coupled to an antenna, it is essential that the primary circuit remain active long enough to build up the secondary oscillations to a maximum, and then if the gap can be made to lose its conductivity the energy in the secondary will not be lost in setting up oscillations again in the primary circuit, but will be sent into the antenna. This desirable property of promptly damping or quenching out the primary oscillations is possessed by both the rotary gap and the quenched gap.

One type of quenched gap is shown in Fig. 2. In view (*a*) is shown the complete device consisting of a number of outer



(*a*) (*b*)

FIG. 2

cooling disks *a* of bronze that hold inner disks across which the sparks pass. Contact may be made by clips to the ridges on the periphery of the outer disks. A series of cooling disks are compressed between clamps so as to make the inner sparking spaces air-tight. In view (*b*) are shown the copper inner disks that are mounted within the cooling disks. Adjacent inner disks are separated by mica rings, and the sparking surfaces, which are covered by silver, are about .01 inch apart.

5. It is customary to allow about 1,200 volts to each gap and as many gaps are placed in series as are necessary for the operating voltage. In the standard sets the gap is composed of a number of copper disks clamped together in a special framework. A metal spring piece is inserted between the contact ridges on the outer disks if the spark gap is to be cut out or short-circuited.

If a nearby station is to be called, the operator is required to lower the voltage of his generator, and to short-circuit a number of gaps, leaving only a few. In this way signals are reduced to such a point as to reach the nearby desired station without disturbing the other stations within the full-power range.

It is customary, in the larger sets, for the copper disks to be single faced, the raised portion being on only one side, while the other side of the disk is perfectly flat. The disk is then placed into the countersunk portion of a large bronze disk, which serves as a cooling surface. These extra cooling surfaces are very necessary, since the sparks can be quenched more efficiently when the gap is reasonably cool.

DAMPED-WAVE TRANSMITTERS FOR SHIP USE

6. Circuits of Damped-Wave Transmitter.—In general, the function of the ship transmitter is to convert an ordinary low-voltage 110-volt direct current into high-frequency oscillations to be radiated from the antenna at a correspondingly high voltage, such as 50,000 volts. The spark transmitter consists essentially of three circuits: 1. Low-frequency, or alternating-current, circuit; 2. closed, or high-frequency circuit; and 3. antenna, or radiating circuit.

The purpose of the low-frequency circuit is to convert the 110- or 120-volt direct current supplied by the ship's generator to the radio room into an alternating current of low frequency and low voltage, for use in the closed circuit. The direct current is made to rotate a motor, which is directly connected to the shaft of an alternating-current generator, which supplies, usually 500 cycles alternating current at 220 volts, for the low-frequency circuit. This is called the motor-generator unit. For the usual 2-kilowatt spark set, this consists of a 220-volt, 2-kilowatt, 500-cycle, single-phase generator, driven by a 120-volt, direct-current, 5-horsepower, four-pole motor at a speed of about 1,600 revolutions per minute. It is generally a two-bearing machine of the oil-ring type. Terminal boxes are secured to the frame of the machine to provide connections to the machine. This alternating current is then supplied to the primary winding of a step-up transformer, having the proper turn ratio to deliver to the closed high-frequency circuit a 500-cycle current at 10,000 to 30,000 volts. The sending key is located in series with this low-frequency circuit, and is used to open or close the circuit, thus making the dots or dashes as sent out by the transmitter. In addition to the sending key, motor-generator, and transformers, the switchboard instruments are considered part of the low-frequency circuit equipment. These consist of an ammeter and voltmeter and a frequency

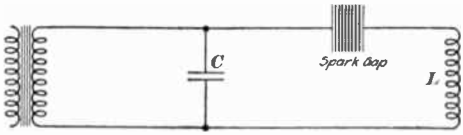


FIG. 3

meter. A switchboard is provided for mounting these instruments, also for mounting the circuit-breaker and instruments for the current from the ship's mains.

7. The function of the closed circuit, shown in Fig. 3, is to convert the 500-cycle, high-voltage, alternating-current supplied from the secondary of the step-up transformer into a high-frequency current of, say, 500,000 cycles (600 meters), at a still higher voltage. In its fundamental form the closed oscillating circuit consists of: Capacity *C*, represented by the condenser, Fig. 3; inductance *L*, represented by the inductance coil *L*, consisting of spirals of copper strip; and a spark gap either of the rotary or quenched type. These three devices are all in series as shown in Fig. 3.

The values of the capacity and of the inductance in electrical units determine the wave-length to which the closed circuit is adjusted. The larger the capacity and the inductance, the longer the wave-length, and vice versa. When the lowest wave-length to be used by any particular set is determined, the capacity is fixed definitely and arrangements made to vary, conveniently, the number of turns of the inductance, thus permitting variation of the transmitting wave-length. Fixed mica condensers each having a capacity of about .002 microfarad and variable inductances are therefore used in the closed circuit. The condensers may be single, two or more in parallel, or two or more in series.

The function of the spark gap in the closed circuit is to allow the condenser to charge to the required potential, then to break down and permit the charge to surge back and forth until its energy is dissipated. The ideal spark gap would be one which would insulate perfectly while the condenser was charging and conduct perfectly on discharging. The quenched-type gap is the nearest practical solution of the problem that has been found.

8. The purpose of the radiating or antenna circuit is to provide the means for transferring the high-frequency oscillations from the closed circuit to the ether. This is accomplished by induction from the helix in the closed circuit to the helix or coupler in the antenna circuit. The separation between the two coils is adjustable in order to provide a loose or tight coupling, as desired. Loose inductive coupling is commonly used. The number of turns in each helix is variable in order to vary the wave-length of each circuit. The antenna circuit consists of the antenna, lightning switch, coupling helix, ground connection, hot-wire ammeter, and wave-change coils.

9. **Wave-Length Limitations and Ranges of Transmitters for Ship Use.**—All ship sets are required by law to be in adjustment for transmission and reception on 300 and 600 meters. Spark sets on shipboard are usually operative between 300 and 3,000 meters. The majority of merchant-marine ships, however, are only adjusted for 300, 600, and 800 meters. The 700-meter wave is coming into use as a working wave-length in place of the shorter ones, which are close to the wave-lengths used by the modern broadcasting stations. The 600-meter wave is authorized for calling purposes or for *S O S* distress calling. The 800-meter wave is used for compass-bearing work.

The sizes of spark transmitters on merchant ships vary from ½ to 2 kilowatts. Small cargo vessels are equipped with ½-kilowatt sets; and ships above 6,000 tons with 2-kilowatt sets. The reliable ranges for this type of damped-wave equipment vary widely according to height of antenna, wave-length, weather conditions, season, and time of day. The following is an estimate of the average range of spark-type equipment for vessels: ½-kilowatt set = 100 miles by day, 150 miles at night; 1-kilowatt set = 150 miles by day, 300 miles at night; 2-kilowatt set = 200 miles by day, and 400 miles at night; and 5-kilowatt set = 300 miles by day, 600 miles at night. On cold nights the above figures are often doubled.

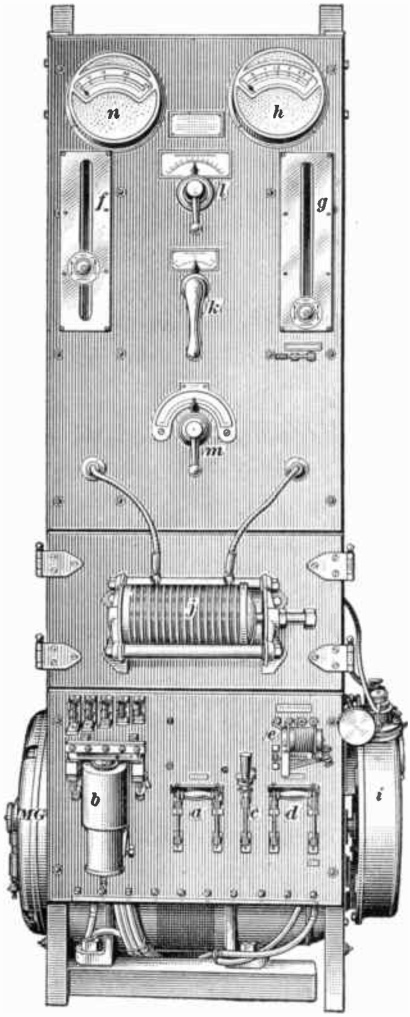


FIG. 4

10. Typical 2-Kilowatt Ship Spark Transmitter. The 2-kilowatt spark-transmitter panel shown in Fig. 4 is fairly typical of the sets used on ships. The circuit arrangement is shown in Fig. 5, the reference letters having the same meaning in both figures. The switch *a*, Figs. 4 and 5, when closed, extends the direct-current circuit from the ship's mains to the automatic motor starter *b*. The switch *c* is in the field circuit of the generator, and the switch *d*

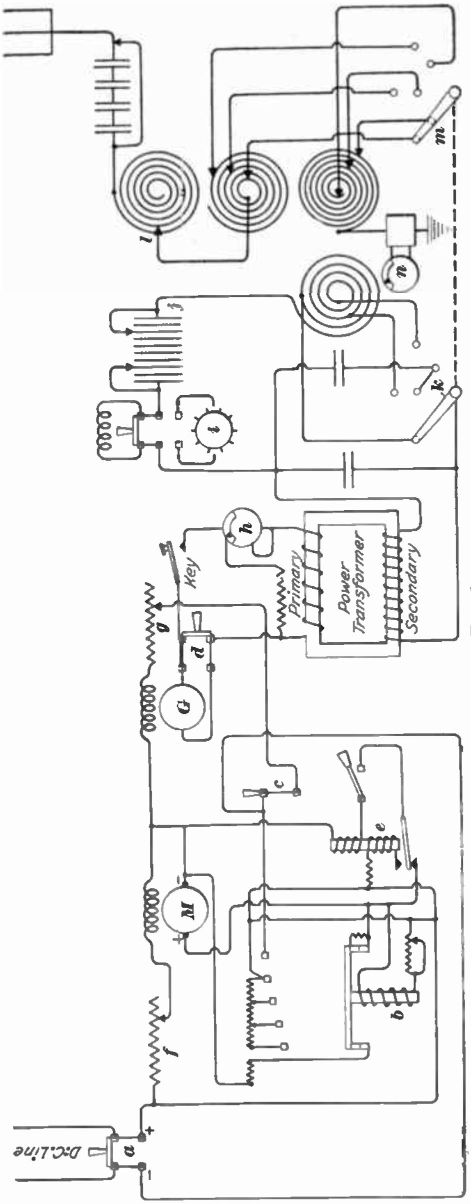


Fig. 5

in the output circuit of the 500-cycle generator. The overload relay is shown at *e*. The current in the field of the motor may be varied by means of the rheostat *f*; the result is a variation of speed with a resultant variation in the frequency of the current in the generator circuit. The generator voltage may be varied by means of the rheostat *g*. The power circuit also includes the wattmeter *h* and the transmitting key. The manner in which these devices operate has been explained in a preceding Section.

From the secondary of the power transformer, Fig. 5, the high-voltage low-frequency alternating current is changed into a high-frequency current in the closed oscillating circuit. Either the rotary gap *i*, Figs. 4 and 5, or the quenched gap *j* may be switched in the circuit. When the rotary gap is used, the clips on the quenched gap are fastened to the same disk, thus short-circuiting the quenched gap. A small inductance coil is in series with the quenched gap when it is in use, to compensate for the inductance of the leads to the rotary-spark gap.

11. The transmitting set, Figs. 4 and 5, is so arranged that the wave-length may be instantly changed from 300 to 600 or 800 meters by means of the wave-change switch *k*. The switch *k* controls two other switches, which, when the switch *k* is moved, cut in the proper amount of inductance and capacity into the closed and open oscillating circuits. Fine adjustments of inductance in the antenna circuit may be made with the switch *l*. The coupling between the open and closed circuits may be varied by means of the lever *m*. The antenna circuit also includes an ammeter *n* for reading the current in the antenna circuit.

12. Factors Limiting Future Use of Damped-Wave Transmitters.—The general tendency of development is toward the use of continuous- or undamped-wave equipment, due to the fact that the interference is greatly reduced, by using undamped waves. More pairs of communication can be carried on at the same time on closely separated wave-lengths when undamped waves are used than when damped waves are used, owing to the sharper tuning of the undamped-wave transmitter. There are many other advantages of the undamped-wave type of transmitter which will be explained later. Many of the ships of the merchant marine are equipped with damped-wave transmitters; but the larger passenger ships and warships have both types.

UNDAMPED-WAVE TRANSMITTERS

ADVANTAGES OF UNDAMPED-WAVE TRANSMISSION

13. Selectivity.—Radio transmission becomes more efficient and more selective the less the antenna oscillations are damped. It has been shown that during the time that the key of an ordinary spark transmitter is closed there are comparatively long periods of inactivity, or time intervals between the trains of wave energy sent out into the ether, even when quenched or rotary spark gaps are employed. A system in which these intervals do not exist, and in which the energy is radiated all the time that the key is closed would obviously be more efficient, since it would radiate more energy in a given time, and, therefore, greater ranges would be possible for the same amount of primary power to the transmitter. It follows that an ideal system would be one in which the waves are not damped at all.

Some of the more important advantages of continuous-wave transmission (C. W.), or of undamped-wave transmission, over damped-wave transmission are as follows: Transmission becomes more selective. This advantage is due primarily to the fact that energy radiated by a spark transmitter is sent out in damped wave-trains. When these wave-trains pass through the receiving antenna they induce a voltage. This voltage causes a current to pass in the primary circuit of the receiver. This current sets up a field which cuts the secondary winding of the receiving circuit inducing therein a voltage, which in turn causes current to pass in this circuit. If these circuits are tuned to the incoming wave, maximum current and signal strength is obtained. However, even if these circuits are somewhat detuned, the damped wave-train will excite them to a considerable extent, causing them to oscillate at their own frequency as well as at the frequency of the signal wave. Thus, the selectivity of reception of a spark signal is fixed, not only by the decrement of the receiving circuit, but by the decrement of the wave-train itself, which, of course, is that of the transmitting station; therefore, more or less interference always exists between spark stations, if the wave-lengths are close to one another.

In the case of a transmitter that is sending out continuous waves, the effect at the receiving station will be somewhat different. When these waves pass through the receiving antenna they cause the circuit to oscillate at the signal frequency alone, because they have no decrement. Therefore, if the receiving circuit is not tuned to resonance with the incoming signal the current set up in the circuit will be very small and the signal strength extremely weak, and this will be true for all conditions of adjustment other than that for resonance. Thus, the selectivity is very good and the station will receive no messages except those for which it is tuned.

14. Range and Efficiency.—The energy radiated from a spark transmitter is spread out over a comparatively large wave-band; that radiated from a continuous-wave transmitter is concentrated into essentially one wave-length. Thus, it follows that the greater the amount of energy that can be concentrated into one wave-length, the greater will be the distance to which this energy will penetrate, and stations may be reached at much greater distances from the sending station than with the spark transmitter; hence the transmission efficiency is greatly improved.

15. Heterodyne Reception.—If the transmitted signal is by continuous wave, heterodyne reception is possible, thus permitting greater amplification than can be obtained in the reception of spark signals. Take for instance, the regenerative type of receiver. When a spark signal is being received, it it possible to carry the regeneration only to a certain limited point where the signal becomes mixed up and is not understandable. On the other hand, if the incoming signal is by continuous wave it is possible to carry the regeneration to a maximum.

When a continuous-wave transmitter is used, it is possible to send and receive on the same antenna at the same time if the proper circuit is inserted in the receiving circuit and if there is a slight difference between the transmitted and received wave-lengths. This would be absolutely impossible with the spark type of transmitter.

The tube transmitter may be adapted to continuous wave, interrupted continuous wave, and phone transmission, and the change may be effected by the operation of a gang switch in the transmitter assembly.

16. Antenna Voltage Decreased.—Since, with the continuous-wave transmitter, the energy is radiated in a continuous stream when a signal is being sent, and not in groups as with the spark transmitter, it follows that for a given amount of energy in the antenna, the amplitude of the oscillations need not be so great. In a damped wave-train the shape of the successive waves is such that the ratio of any maximum to the next one following is a constant. The rate of decrease of the amplitudes in a wave-train is also indicated by the *logarithmic decrement*, which is defined to be the natural logarithm of the ratio of two successive maxima in the same direction. As an example, consider the case of a spark transmitter operating on a wave-length of 300 meters with a decrement of .1, the spark gap breaking down 1,000 times per second. The number of complete oscillations in a circuit when the amplitude of the last oscillation has been reduced to 1 per cent. of the initial oscillation, is equal to the sum of the constant 4.605 plus the decrement divided by the decrement, or

$$\text{Number of oscillations per spark} = \frac{4.605 + .1}{.1} = 47.05$$

Therefore, for every spark there will be 47.05 oscillations and for 1,000 sparks there will be 47,050 oscillations. The frequency will be equal to the constant 300,000,000 divided by the wave-length, which in this case is 300.

$$\text{Frequency} = \frac{300{,}000{,}000}{300} = 1{,}000{,}000 \text{ cycles per second;}$$

thus, the frequency will be 1,000,000 cycles per second and the time per second during which energy is radiated is equal to the total number of oscillations divided by the frequency, or

$$\frac{1{,}000\times\frac{4.6+.1}{.1}}{1{,}000{,}000}=.047 \text{ second}$$

It is found that energy is radiated for only .047 second and this is 4.7 per cent. of the total time. Comparison of this with the case of the continuous-wave transmitter shows quite a difference, since with the latter the time per second during which energy is radiated is 100 per cent.

It follows, therefore, that if much power is to be radiated by the spark type of transmitter, comparatively high-oscillation amplitudes must be used, which means that relatively high voltages must be employed, since energy is radiated only during a small fraction of the time, whereas, with the continuous-wave transmitter, much lower voltages could be used, with subsequently lower oscillation amplitudes, to obtain the same power output. Thus, for a given power output, in using the spark transmitter, the antenna system would be under a much greater voltage strain than in the case of the tube transmitter giving the same output. Moreover, a given antenna system will have a greater possible energy radiation on continuous waves, thus decreasing the construction difficulties encountered in extremely high-voltage apparatus.

17. Adjustment of Signal Note.—With spark reception the signal note is determined by the transmitter-group frequency, while the note received from a continuous-wave transmitter may be varied between wide limits and the operator at the receiving station may adjust the latter to that pitch which is the easiest for him to copy and to distinguish from strays or static. This feature of being able to adjust the note also helps very much in the reading of any one signal through interference, since the desired signal may be tuned to a note that will be slightly different from that of any of the signals that are giving interference and this difference in pitch is usually enough to enable the experienced operator to get the message that he is after through the signals that are causing him interference.

CLASSIFICATION

18. Modern transmitting systems employing the undamped wave are classified as follows: The alternator; the arc; the timed spark; and the vacuum tube. The fundamental principle of operation of each of these systems has been treated elsewhere. Many additions and refinements have been made in the commercial adoption of these systems. A brief description of each of these systems with their auxiliary apparatus will therefore be of interest.

ALEXANDERSON SYSTEM

19. The Alexanderson high-frequency alternator, as installed at the majority of the high-power telegraph stations in the United States, is capable of delivering 200 kilowatts of radio-frequency energy at 25,000 cycles or less. It consists essentially of a two-phase motor *a*, Fig. 6, driving a high-speed generator *b* through a step-up gearing. This generator contains a steel disk rotor that contains a large number of slots on its periphery filled with non-magnetic material (bronze). These slots cause magnetic fluctuations when the disk rotates, and alternating currents are induced in the armature coils, which are stationary and wound in slots adjacent to the disk. There are 64 armature coils and these are coupled to a large common secondary, which is connected to the antenna and ground system. The magnetic circuit is energized by the current in the stationary field coils.

One of the armature coils is led to an independent circuit, and the current from it is rectified by a small vacuum rectifier tube and is then used for operating the speed regulator. The actual regulation is accomplished through a reactance coil, which in turn changes the voltage supply of the driving motor. This method of regulation is very accurate and sensitive. Any

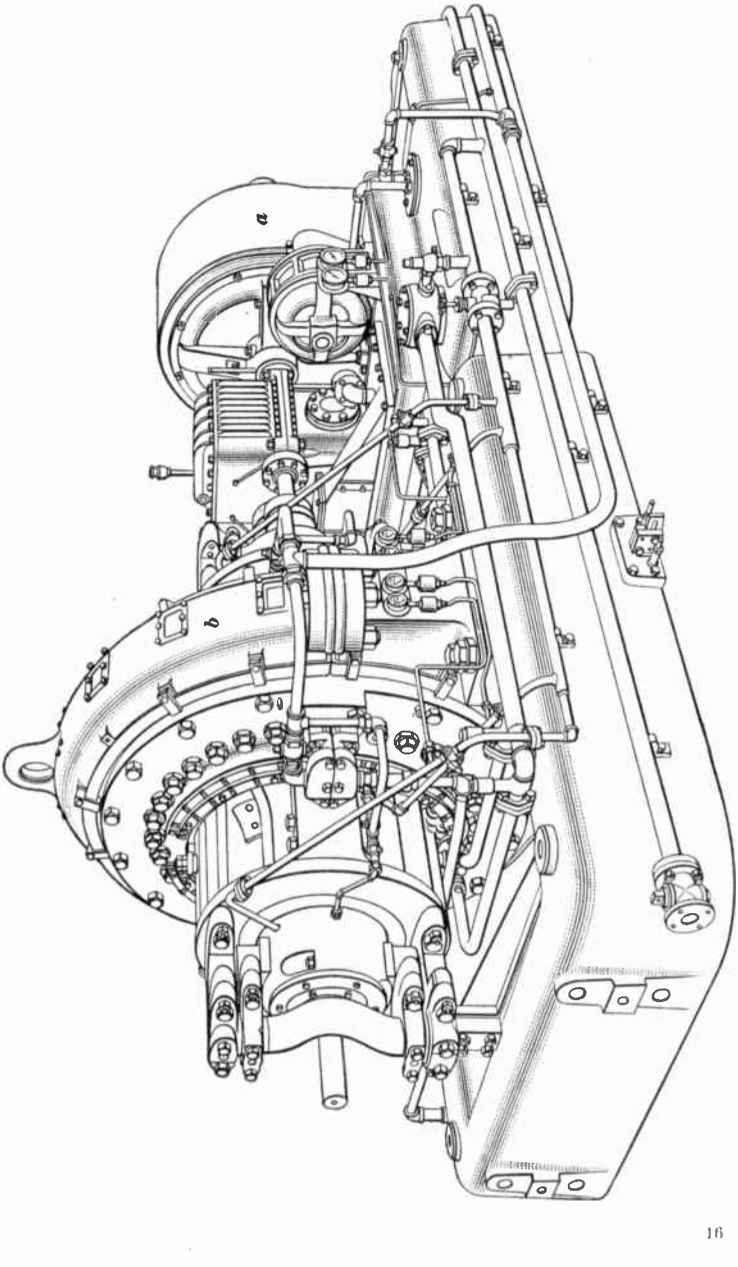


FIG. 6

wave-length desired, within the design limit of the machine, can be obtained by changing the speed of the machine, which is accomplished by the turning of one control handle.

20. A schematic diagram of the Alexanderson alternator connected to an antenna system is shown in Fig. 7. The armature coils of the alternator *a* are each connected to separate windings in the primary *b* of the oscillation transformer. The secondary winding *c* is connected directly in the antenna circuit.

The antenna *d* is of the multiple-tuned type, where a number or down leads are employed, each connected to an independent outdoor tuning coil *e* and common ground system. The antenna

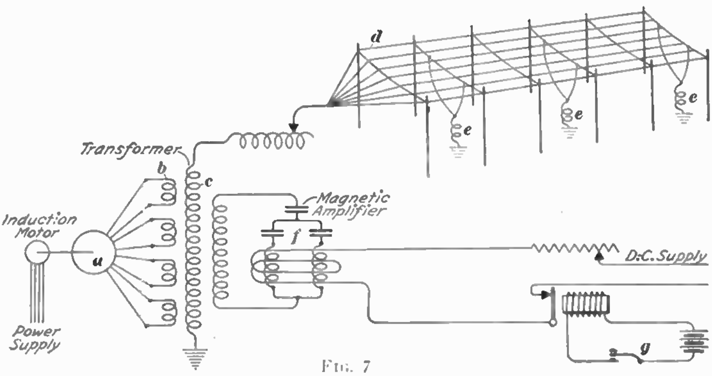


FIG. 7

efficiency is thereby greatly increased, and a greater antenna current is obtained with the same power input than would be otherwise possible. The alternator equipment is fully protected, and has automatic alarms which shut down the machine in case of failure of proper supply of oil and water to the various cooling systems.

Keying is effected through a magnetic amplifier *f*, an apparatus operated by small values of direct current which in turn has the effect of throwing the alternator in or out of resonance with the antenna system. A telegraph key *g* controlling through a relay the direct-current supply to this magnetic amplifier, therefore causes the high-frequency current in the antenna to be switched on and off correspondingly and telegraphic signaling is secured.

21. A more detailed drawing of the magnetic amplifier is shown in Fig. 8. It consists essentially of two windings *a* and *b*, wound on a specially formed magnetic core *c*. The winding *a* is made up of two separate coils connected in parallel and across the coil *d*. The coil *d* is coupled to the antenna circuit. The winding *b* is wound on both legs of the magnetic core in such a manner that the flux produced by the winding *a* strikes the coil *b* in opposite directions and no voltages can be induced in it by the current circulating in the coils *a*. The

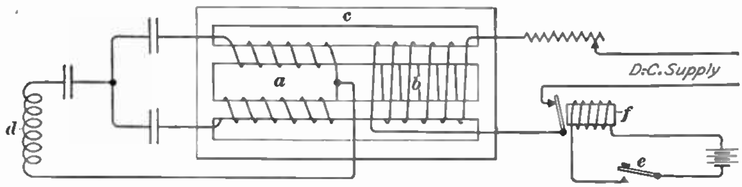


FIG. 8

radio-frequency currents that may circulate in coil *a* cannot, therefore, have any effect on the coil *b*.

With the transmitting key *e* open, the circuit of the winding *b* is closed through the back stop of the relay *f*. When in this condition the core *c* of the magnetic amplifier is saturated, and hence an increase of current in the winding *a* will not increase further the number of lines of force except for the number of lines of force that would be set up even if no iron core were present. The inductance of the circuit including the coils *a* and *d* is thereby reduced, which also affects the antenna coil and reduces its inductance. This further detunes the antenna circuit, so that it is out of resonance with the alternator; and the energy now set up in the antenna is just 9 per cent. of that when resonance obtains.

When the key *e* is closed, the relay *f* becomes energized and draws its armature away from the back contact. This results in the opening of the circuit through the winding *b*; the core *c* is then no longer saturated. The inductance of the path through the coils *a* and *d* is increased, which in turn affects the antenna coil to which coil *d* is coupled. The circuits are so arranged that with the key *e* closed the core *c* is not saturated, resonance obtains between the generator and the antenna circuits, and maximum energy is sent out into the ether.

COMMERCIAL ARC TRANSMITTERS

USE OF ARC TRANSMITTERS

22. Arc transmitters are used for both low- and high-power radio-telegraph communication. From 50 per cent. to 100 per cent. greater ranges are obtained with the arc transmitters than with the spark-type transmitters. For wave-lengths below 1,000 meters the arc sets are very unstable and inefficient and for this reason the commercial application of the arc is limited to the longer wave-lengths.

The wave-lengths for high-power transmitting stations vary between 5,000 and 25,000 meters. Reliable communication, throughout the year, is now possible across the Atlantic Ocean, over distances of 3,000 to 4,000 miles, by use of high-power arc and alternator equipment. A great advantage has been obtained by the use of undamped waves for transmission over long distances, where the daylight absorption is great and a long wave is found more desirable. Daylight absorption is less on the long wave-length than on the shorter waves below about 3,000 meters.

FEDERAL 2-KILOWATT ARC TRANSMITTER

23. Circuit Diagram and Operation of Set.—Radio transmitters are designed and constructed with a view to their ultimate power output. In the case of arc sets, the power output is usually reflected in the construction of the arc chamber and its auxiliary apparatus. The same principle of operation, however, holds true for both the low- and high-power arc transmitters. To explain the construction and operation of a commercial arc transmitter, the Federal 2-kilowatt set will be used.

The operation of an arc transmitter is dependent on the formation of an arc between two electrodes. In the transmitter represented in Fig. 9 the energy required by the arc is supplied by the direct-current generator *a*. The current passes from the positive terminal of the generator, through the electromagnet *b*, copper electrode *c*, carbon electrode *d*, to the negative terminal of the generator. The antenna or radiating circuit includes the antenna *e*, series condenser *f*, loading inductor *g*, variometer *h*, front contact and armature of the key relay *i*, ammeter, resistance *j*, electrodes *c* and *d*, and ground. When the transmitting key *k* is closed, the relay *i* draws up its armature and completes the antenna circuit. Undamped oscillations are set up in the antenna circuit and continue as long as the transmitting key *k* is closed.

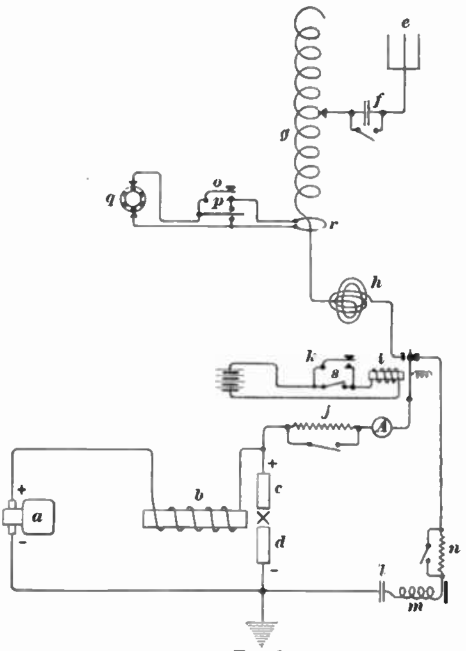


FIG. 9

When the key *k* is opened the generation of oscillations is not stopped, but rather shifted to the *back-shunt*, or *dummy-antenna*, circuit. This circuit resembles the antenna circuit in that it possesses capacity represented by the condenser *l*, inductance represented by the coil *m*, and resistance represented by the resistor *n*. By operating the key *k* the generation of oscillations is shifted alternately from the antenna to the dummy-antenna circuit as required for transmitting a message. The arc is, therefore, active throughout the entire time that the set is in operation.

24. The method of signaling with the key *k*, Fig. 9, just described, is known as the back-shunt method. The energy in the antenna circuit may also be modified by means of the auxiliary key *o*. This key is provided with a single-pole double-throw switch *p*, which, when in contact with its upper stop, short-circuits the key *o*; when in contact with the lower stop, the switch short-circuits the chopper *q*; when the switch *q* is in its intermediate position, in contact with neither stop, the key *o*, the chopper *q*, and the single turn *r* coupled to coil *g*, are all connected in series.

To transmit signals with the key *o*, the antenna circuit must be closed through the front contact of the relay *i*. This may be done either by closing the short-circuiting switch *s* of the key *k* and holding the armature of relay *i* magnetically against its front stop, or by placing an insulating wedge between the armature and its back stop and thus mechanically holding it in contact with the front stop.

In order to transmit undamped, or continuous, waves (C. W.) the switch *p* is brought in contact with the lower stop. This short-circuits the chopper *q*, and places the loop *r* in series with the key *o* only. If under this condition the key *o* is closed the inductance of coil *g* will be changed and the transmitted wave will be on a different wave-length. The antenna inductor *g* must then be so arranged that it transmits on the proper wave-length when the key *o* is closed.

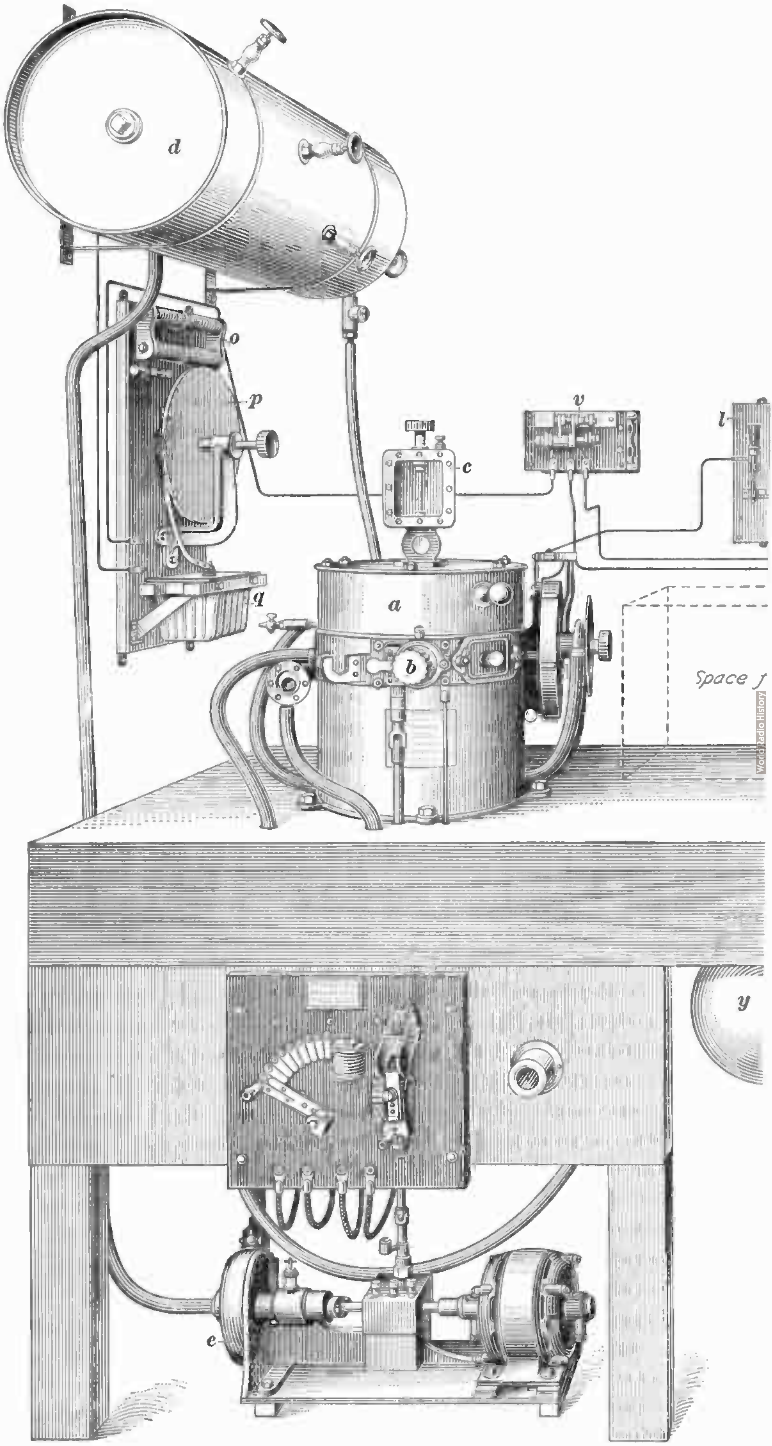
For interrupted continuous-wave (I. C. W.) transmission the switch *p* is in its intermediate position. The inductance of the antenna coil *g* is then modified not only by the operation of key *o*, but also by the chopper *g*. Each dot and dash will be sent out as a series of audio-frequency pulsations.

The chopper *q* may also be used in connection with the key *k*. The switch *p* is brought in contact with its upper stop so as to short-circuit the key *o*. The dots and dashes formed by the key *k* will then be modulated or broken up by the action of the chopper *q*.

The resistances *j* and *n* are provided with short-circuiting switches, which are closed when greater power is required. The antenna condenser *f* is also provided with a short-circuiting switch, which is closed when transmission takes place on the longer wave-lengths. Wave-length adjustments are made on the antenna coil *g*, while the final or vernier adjustment is made with the variometer *h*. The ammeter in the antenna circuit shows the value of current in that circuit. Other current and voltage measuring instruments are provided, but these are not shown in the illustration.

25. The various units of the Federal Telegraph Company's 2-kilowatt arc transmitter are shown mounted and interconnected in Fig. 10. The arc converter *a* consists of a chamber in which may be found the anode and the cathode. The carbon holder *b* is latched into position and is so arranged as to engage a key in the slot of a member that rotates slowly while the set is used for transmitting purposes, thus insuring an even consumption of the carbon electrode. The electromagnets are located near the top and bottom of the container. Above the container is the alcohol or hydrocarbon feed-cup *c*, and it is so arranged that the proper number of drops of liquid is permitted to enter the arc chamber. The introduction of the alcohol assists in dispersing the ions of the arc. The enclosing chamber of the converter is so constructed as to provide ample water cooling surface for efficient operation. The cooling water tank *d* is connected through suitable piping with the centrifugal pump *e*, the latter forcing the water through the cooling compartment of the arc chamber.

The control panel contains a direct-current ammeter *f*, and a direct-current voltmeter *g* for determining the current and voltage, respectively, in the direct-current generating circuit; a radio-frequency ammeter *h* for determining the value of the current in the oscillating circuit; the arc main-line switch *i*; starting-resistance switch *j*; and the set supply switch *k*. On the left of the control panel is shown a resistor *l*, which is sometimes connected in the antenna circuit when low-power transmission is desired. The resistor can be short-circuited by the switch. The motor-generator controls are shown in the lower left-hand corner of the figure. The antenna circuit includes the inductance coil *m*, and the series condenser *n*; the dummy antenna,



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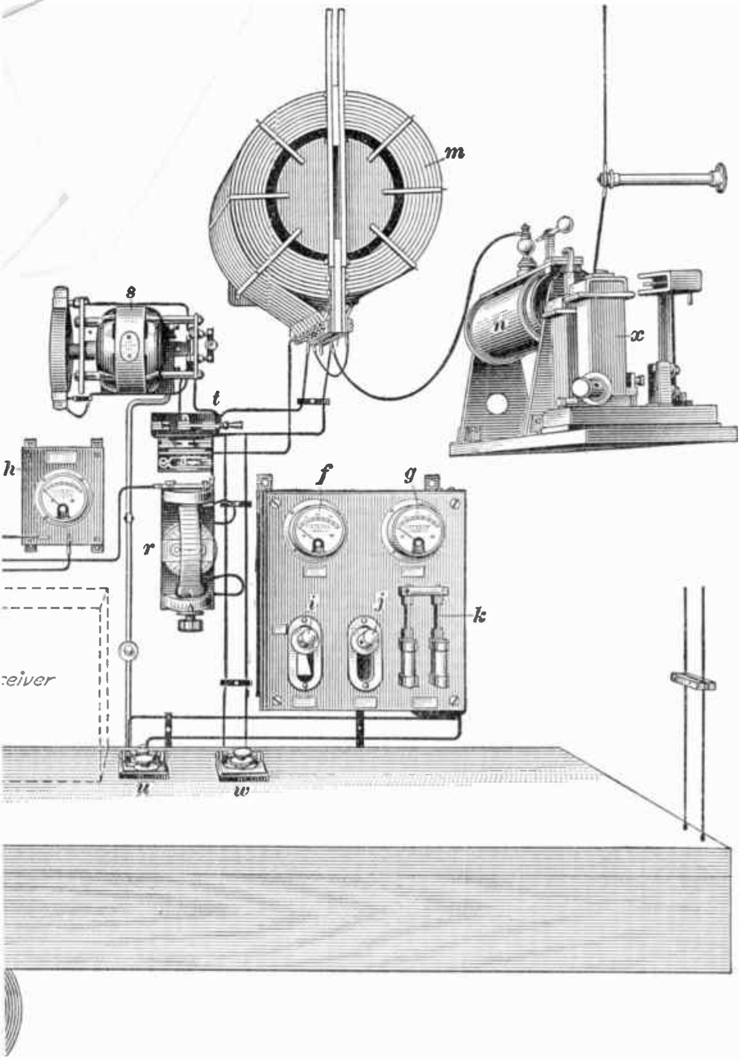
m
s
n
x
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w

or back-shunt circuit shown at the extreme left of the figure, is made up of the fixed resistor *o*, the variable resistance *p*, and the condenser *q*. The antenna circuit also includes the variometer *r* which is used by the operator to make slight changes in the wave-length. The chopper *s* may be switched into the antenna circuit by means of the switch *t* when interrupted continuous-wave (I. C. W.) transmission is desired. The operation of the Morse key *u* operates the back-shunt relay key *v*, which, when the key is closed, completes an oscillating circuit through the antenna. When the key *u* is open, the relay key completes the oscillating circuit through the back-shunt devices. The auxiliary hand key is shown at *w*.

The switch *x* may be placed in any one of three positions. In one position it connects the transmitting equipment with the antenna; in its second position it connects the receiving equipment, not shown, with the antenna; and in its third position it grounds the antenna. The arc pressure regulator *y* controls the density of the gas in the arc chamber. The dotted rectangle represents the space reserved for the receiver.

MARCONI TIMED-SPARK TRANSMITTER

26. The English Marconi Company developed and later brought to a high degree of perfection a system for producing and transmitting undamped waves, using a number of specially timed spark transmitting circuits. The ordinary spark system, with a disk discharger or rotary gap, sets up groups of oscillations at regular intervals, and the wave energy in the antenna circuit is less damped than with the old fixed open-gap system. These oscillations, and their resulting ether waves, are in groups

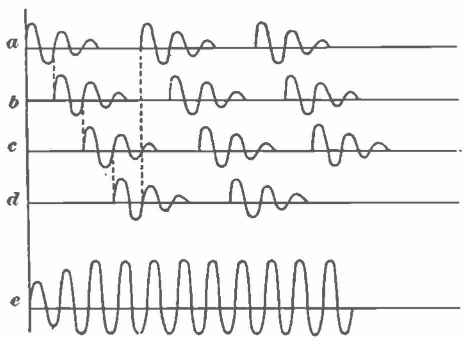


FIG. 11

separated by definite time intervals. The function of the timed-spark discharge transmitter is to fill up these intervals of time with other groups of oscillations, which are set up by other discharge circuits. The idea is similar to using a six-cylinder engine in place of a single-cylinder one. In Fig. 11 is shown the general idea of the method. The lines *a*, *b*, *c*, *d* show groups of discharges set up in four different circuits, so arranged that the discharges of the different circuits follow each other in a regular sequence. It is then obvious that if these discharges are made to act inductively on a collecting

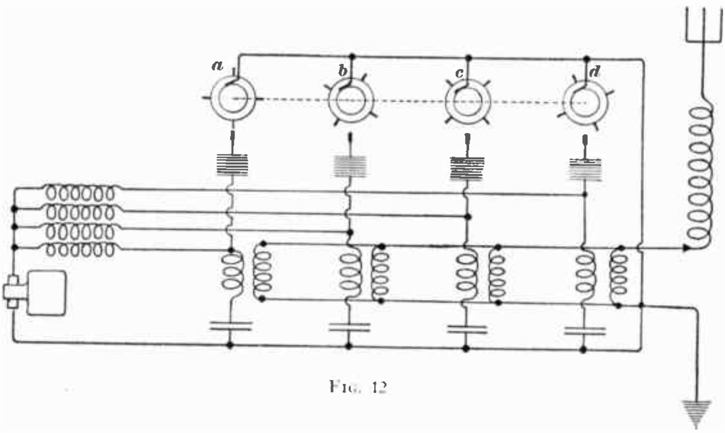


FIG. 12

circuit, the resulting oscillations in this circuit will have undamped characteristics as shown by the wave form at *e*. The adjustment so that the discharges do not overlap each other in phase is somewhat critical to maintain. Two of the foreign high-powered transatlantic stations are now using this method for undamped-wave telegraph communication with good results.

27. A schematic diagram of a timed-spark transmitter is shown in Fig. 12. The rotary gaps *a*, *b*, *c*, and *d* are fixed to the same shaft in such a manner that a discharge takes place across each gap at a different interval. A rotary and a quenched spark gap are included in each circuit. When the high-voltage direct current is impressed across the electrodes a discharge takes place, which starts an oscillating current, say in the circuit of the gap *a*. By induction the energy is transferred to the antenna circuit. The discharges across the second, third, and fourth gaps follow in close succession, and thus maintain the current in the antenna circuit at constant amplitude.

ELECTRON-TUBE TRANSMITTERS

TUBE-ATTACHMENT SET

28. The first step in the change over from spark to tube transmitters for ship use is found in the application of the tube attachment set. This transmitter is shown schematically in Fig. 13 and is designed to be operated from the same source of power as the 2-kilowatt type of quenched-spark transmitter, which employs the same motor-generator set. It is so arranged that by means of a change-over switch *a* the operator may throw on either the spark set or the tube set. This is a means of gradually educating the operator to the use of the tube set and generally results in the use of the tube set the majority of the time as soon as the operator becomes familiar with its operation.

The tubes *b* and *c* used in this circuit are of the 250-watt type. The filaments of these tubes are heated from the alternating-current supply by means of the step-down filament transformer *d*, which supplies 3.75 amperes to each filament at 11 volts. When the filament switch *e* is closed, the amount of current supplied to the tubes is regulated by means of the filament rheostat *f* in the primary side of the circuit. It is advantageous to have the control rheostat in the primary side, as in this case its current-carrying capacity may be much smaller than if it were placed in the secondary side, as the current in the secondary is approximately ten times as great as in the primary. The same high-voltage transformer *g* that is used in connection with the 2-kilowatt spark set is also used with the tube set. This transformer gives 12,500 volts on the secondary side when 110 volts is applied to the primary through a switch connecting to the 110-volt 500-cycle supply circuit. A resistance *h* is inserted in series with the primary winding so that the secondary voltage may be controlled. The plate of each tube is connected to an end of the transformer. The normal direct-current plate voltage of these tubes is rated at 2,000 volts, but this value may be increased 100 per cent. for alternating current without damaging the tube. This would mean, since the mid-point of the secondary winding is at ground potential, that if 4,000 volts were supplied to each plate, there would be 8,000 volts across the secondary. Owing to the drop in the secondary voltage with normal load on it, it is only necessary to insert a small amount of resistance by means of the plate rheostat to get the desired voltage on the plate.

The two .004-microfarad condensers *i* connected in series directly across the secondary of the plate transformer are for the purpose of raising the natural frequency of the circuit from one side of the secondary through the 30-millihenry choke coil *j* and from plate to filament of one tube back to the mid-point of the secondary, so that it will not be in resonance with the applied frequency. Without these condensers there would be a case of audio-frequency resonance and the voltages in this circuit would reach abnormal values with subsequent breaking down of the circuit, probably in the bushings where the secondary leads come out of the transformer. The 30-millihenry coils are for the purpose of keeping any radio-frequency current from getting back into the part of the circuit ahead of these chokes. The two .004-microfarad condensers *k* connected directly across the two plates serve to isolate the oscillating circuit from the high-voltage source, and to enable the plates to be connected (from a radio-frequency viewpoint) in parallel, without short-circuiting the source. The milliammeter *l* in the lead from the mid-point of the plate transformer secondary to the ground shows the amount of plate current taken by the two tubes and should be around 125 milliamperes.

29. The grid-leak resistance *m*, Fig. 13, is connected from the two grids, in parallel, to the ground and should be about 10,000 ohms. The grid lead is connected to the oscillating circuit as shown, and the .004-microfarad condenser *n* in series

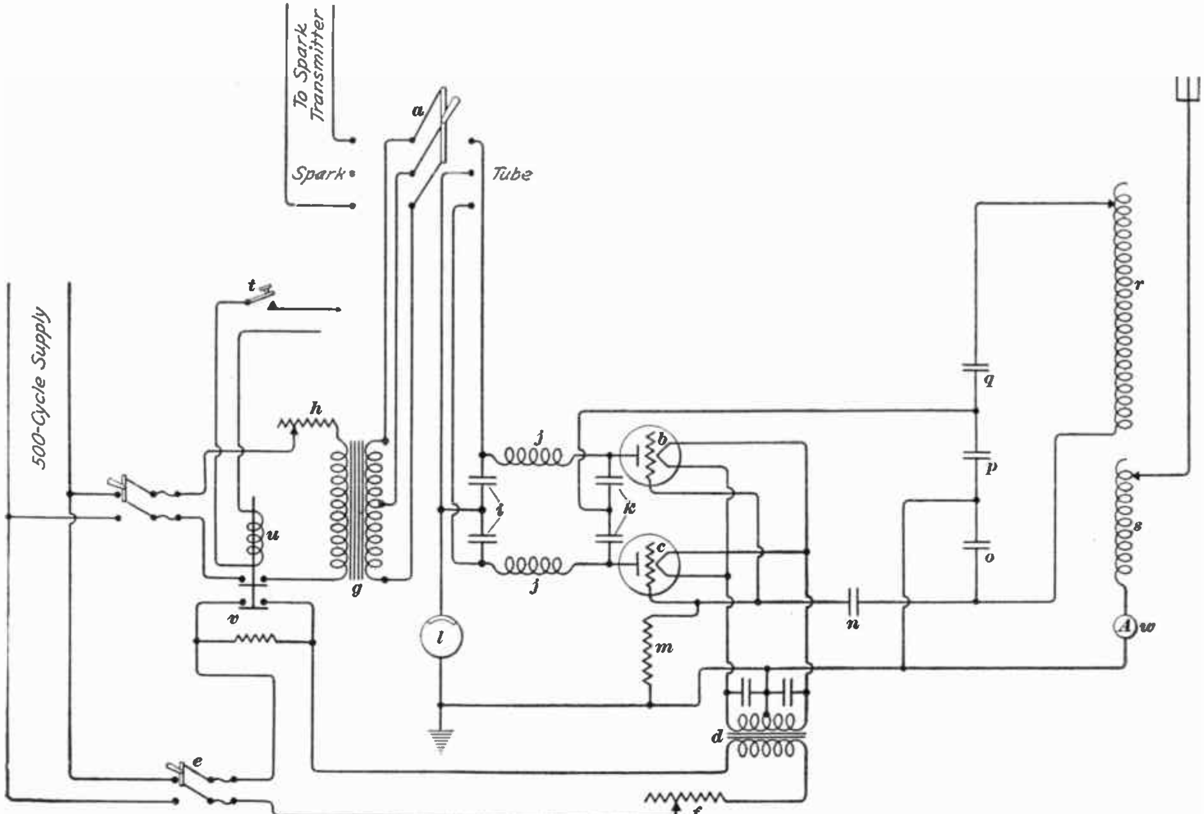

To Spark Transmitter
Spark
Tube
500-Cycle Supply
a
t
h
u
g
v
e
f
d
m
l
j
i
k
b
c
n
q
p
o
r
s
A
w

Fig. 13

with this lead serves to block any direct current from passing in this circuit and, therefore, causes the direct current to pass through the grid-leak resistance to the ground, thus putting the necessary operating bias on the grids of the tubes. The grid excitation voltage is that across the grid condenser *o*, which has a capacity of .078 microfarad. The plate condenser *p* has a capacity of .008 microfarad. The .02-microfarad condenser *q* is for the purpose of giving an autotransformer effect and thus stepping up the voltage across the inductance in the oscillating circuit to get the necessary amount of current in this circuit. The energy from the closed oscillating circuit, or tank circuit, is passed into the antenna circuit by means of the inductive coupling between the tank inductance *r* and the antenna inductance *s*. The antenna current obtainable when this circuit is properly adjusted is in the neighborhood of 10 amperes when the antenna resistance is 4 ohms and the antenna capacity is .002 microfarad.

The telegraph key *t* is in the primary side of the plate transformer. When the key is pressed it operates a relay *u*, whose contacts make and break the circuit through the primary winding of the plate transformer *g*. There is also an auxiliary set of contacts on this relay which are isolated from those just mentioned, and when these contacts are closed they short out the compensating resistance *v* in the filament circuit. If this means of compensation or some other means were not employed and the filaments were adjusted to proper brilliancy with the key open, owing to the drop in primary voltage when the key was pressed the filaments would correspondingly drop below normal and would not be operating at the proper point. Therefore, the filaments are adjusted with the key down and the compensating resistance cut out, and then the key is opened and the resistance adjusted to that value which allows normal current to pass through the filaments of the tubes. Thus there is no change in the filament current, whether the key is closed or open. An ammeter *w* in the antenna circuit provides a means for determining the value of the current in the antenna circuit.

This type of circuit is very good for ship use, as it allows very little reaction on the tank, or closed oscillating, circuit owing to changes in the antenna circuit. For instance, as the ship antenna swings from the motion of the ship and the wind, there will be a change in the antenna capacity, which, if allowed to react on the oscillating circuit, would cause the frequency to change, thus giving a note of varying frequency, which might vary so much as to be unreadable at the receiving station. It might go completely out and then come in again. This circuit also eliminates harmonics to a great extent.

200-WATT VACUUM-TUBE TRANSMITTER

30. Flexibility of Transmitter.—The vacuum-tube type radio transmitter lends itself to a greater number of uses than any other heretofore developed. Not only does it perform the functions of the spark transmitter, but it also provides continuous-wave telegraph transmission and radio-telephone communication. This transmitter is rated at 200 watts since it employs four 50-watt vacuum tubes as oscillators for transmitting undamped-wave telegraphy, thus giving a combined output of 200 watts in the antenna circuit. The set is designed for radio telegraph or telephone use either on ships or at shore stations. Transmission by means of the usual ship-type antenna is provided for on any wave-length between 300 and 800 meters. By the use of additional loading coils known as the long-wave attachment, especially built for the set, it is possible to transmit undamped-wave telegraphy (C. W.) on wave-lengths from 1,000 to 2,000 meters.

31. Circuit Connections.—A complete circuit diagram of a 200-watt tube transmitter is shown in Fig. 14 (*a*). A simplified diagram of the set is indicated in view (*b*). The source of high-frequency energy for this transmitter is the vacuum tube, which acts as a converter, changing the high voltage supplied by a direct-current generator, to a high radio-frequency current. In this set, four 50-watt tubes are used to establish undamped- or continuous-wave (C. W.), or interrupted continuous-wave (I. C. W.) telegraphy, and are known as oscillator tubes, that is, generators of radio-frequency energy. For radio telephony two tubes are used as oscillators, two as modulators, and one additional tube as a speech amplifier.

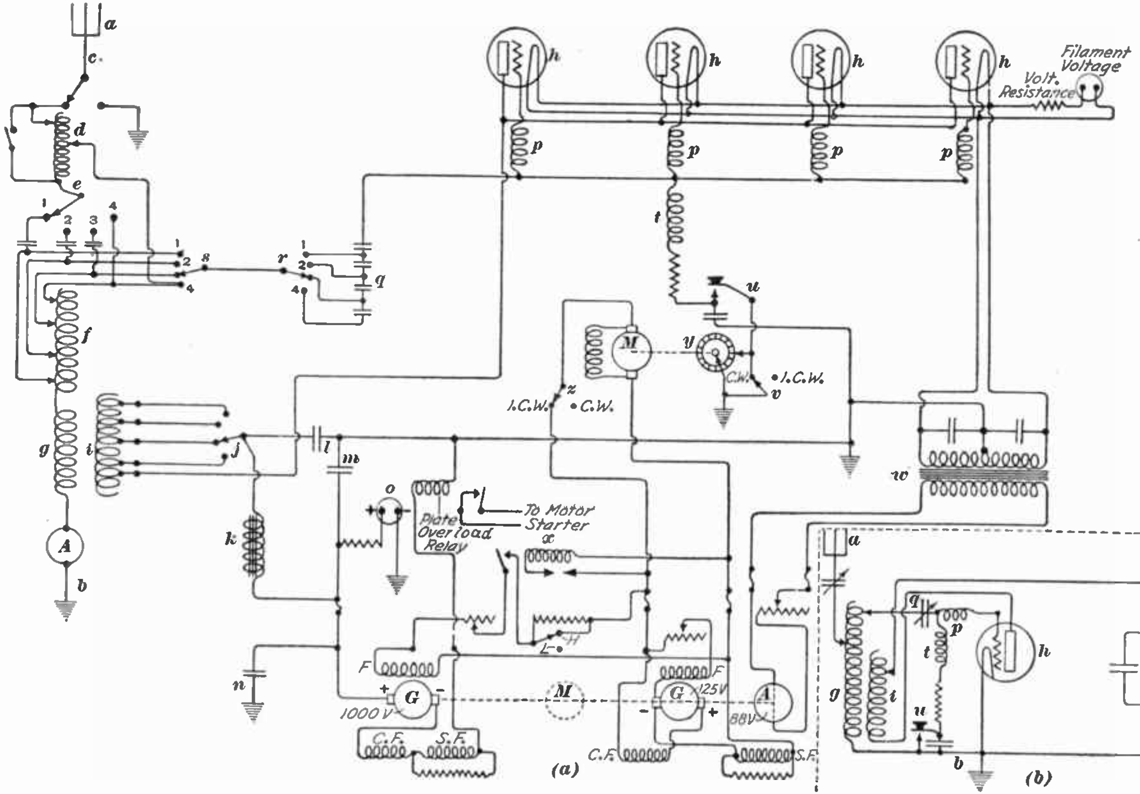
In the following discussion reference will be made to the more complete diagram of view (*a*). The operation of the set will be more apparent by referring to the simplified diagram of view (*b*).

32. A vacuum-tube transmitter consists of at least four fundamental circuits: The antenna circuit, the plate circuit, the grid circuit, and the filament circuit. The antenna circuit comprises, besides the antenna *a*, Fig. 14, and ground *b*, a series of coils and condensers necessary for tuning the circuit to the exact wave-length. The lightning switch *c*, when thrown to the right, grounds the antenna; this connection is made whenever the set is not in use. When the switch *c* is in the position shown, the various loading coils and condensers are connected in the circuit. The first of these coils is the extra loading coil *d*. The inductance of this coil may be varied, but on the shorter wave-lengths this coil may be entirely cut out by means of the short-circuiting switch shown on the left of the coil.

The switch *e* has four contact points. When in contact with point *1*, minimum wave-length obtains, and when on point *4* transmission takes place on the maximum wave-length. Intermediate wave-lengths may be obtained by placing the switch arm on contacts *2* or *3*. The condensers in series with points *2* and *3* are omitted when the long-wave coil system is used.

The loading coil *f* is adjusted to four different wave-lengths by means of clips placed on the proper turns. The clips are connected to the switch points of the switch *e*. The antenna generating coil *g* receives the energy from the plate circuit, and sets up high-frequency voltages in the antenna circuit. The value of the antenna current is determined by means of the ammeter.

33. The *plate circuit* connects the plates of the transmitting oscillator tubes *h*, in parallel, through the plate coupling coil *i*, switch *j*, reactor *k*, and fuse to the positive side of the 1,000-volt generator *G*. The negative terminal of this supply is connected to the filament circuit of the tubes through the



a
c
d
e
1
2
3
4
s
r
q
f
g
i
j
k
l
m
n
o
A
b
h
p
t
u
y
M
v
z
w
x
I.C.W.
C.W.
Filament Voltage
Volt. Resistance
To Motor Starter
Plate Overload Relay
G
1000 V
C.F.
S.F.
F
125V
88V
H
L
(a)
(b)

Fig. 14

plate overload relay. The plate coil *i* is wound on a tube that is placed outside of but concentric with the tube on which the generating section *g* of the antenna inductance is wound, thus providing sufficient coupling between the two windings *i* and *g*. The plate coil *i* acts as the primary of the oscillation transformer and is provided with taps to permit adjustments to obtain the best output and most efficient adjustments for the set. The plate circuit further includes a reactor condenser *l*, a filter condenser *m*, and a protective condenser *n*. The plate voltage may be read directly on the plate voltmeter *o*.

34. The *grid circuit* of the transmitting set starts with the grid elements of the oscillator tubes *h*, Fig. 14, in parallel, through the radio choke coils *p*. the variable capacity coupling *q*, switch arms *r* and *s*, and coils *f* and *g*, to the ground. Since the filament circuit is also grounded, the common ground constitutes the grid return to the filament. When the long-wave coil system is used the connection from contact *4* of the switch *s* to coil *f* is opened. On the shorter wave-lengths the connection from point *4* to coil *f* is closed, and the connection from point *4* to coil *d* is opened. The switches *r* and *s* permit of tuning the grid circuit to the desired wave-length.

The grid-leak resistance circuit may be traced from the grid elements of the tubes through the choke coils *p*, grid-leak choke and grid-leak resistance *t*, the telegraph key *u*, and switch *v* to the ground.

The filament circuit is from the filaments of the tubes *h* through the filament transformer *w* to the 88-volt alternator. The filament current is controlled by means of a rheostat in the primary circuit of the transformer *w*. The by-pass condensers across the secondary of the filament transformer *w* provide the path necessary for radio-frequency currents. The mid-point of the secondary of the transformer *w* is grounded.

35. The 1,000-volt generator, the 125-volt generator, and the 88-volt alternator are all driven by the same motor *M*, which may be either of the alternating- or the direct-current type. The separately excited field *F* of the 1,000-volt generator *G* receives its current from the 125-volt generator. The field relay *x* opens the circuit of the separately excited field winding of the 1,000-volt generator when the operator is receiving a message. Directly below the relay is the power control resistance, which is short-circuited when normal power is used. The designations *H* and *L* near the power-control resistance switch signify *high* and *low*, respectively, which have reference to the power used. The designations *C. F.* and *S. F.* near the 1,000- and 125-volt generators signify *commutating field*, and *series field*, respectively.

36. Generation of Oscillations.—When the starting switch is closed an instantaneous surge occurs in the plate circuit, with the result that the antenna is forced into feeble oscillations whose period depends upon the inductance and capacity of the antenna circuit. The grid circuit, due to its capacity relation to the antenna withdraws some of this oscillating energy with the result that an oscillating potential is applied to the grids of the tubes. This produces a change in the plate circuit, which, if the circuits are properly arranged, adds to the effect of the original surge. This cycle of operation is then repeated with the antenna current continually increasing until limited by the antenna resistance and tube output characteristics.

37. Method of Keying for Continuous-Wave Telegraphy. In order to telegraph by the use of continuous waves, means are provided whereby the operation of the telegraph key *u*, Fig. 14 (*a*), starts and stops the generation of high-frequency energy. The transmitting key *u*, when closed, shunts the key condenser and completes the direct-current path from the oscillator grids to the neutral tap of the filaments, through the grid leak, thus placing the proper grid potential on the oscillator grids to permit oscillations. When the key is opened, the key condenser is cut into the grid circuit, opening the direct-current path, and placing a sufficiently high negative potential on the grids of the tubes to stop or block oscillations.

38. Interrupter for Interrupted Continuous-Wave Telegraphy.—For transmitting on interrupted continuous-wave telegraphy (I. C. W.) a motor-driven chopper or interrupter *y*,

Fig. 14, is used. The function of this chopper is to start and stop oscillations of the set the same as does the key used on continuous-wave telegraphy, except that the oscillations are started and stopped at an audio-frequency rate of normally 500 cycles while the chopper is running. When the signal switch *z* is thrown to the interrupted continuous-wave position, the interrupter motor is started and the transmitting key is connected in series with the chopper.

39. Telephone Features.—In addition to the two methods of communication that have been described, this transmitter is also provided with the necessary apparatus for radio telephony. In order to carry on telephone communication it is necessary to provide apparatus capable of moulding or modulating the high-frequency energy. That is, an envelope, the shape of which resembles that of the voice waves, is formed around the high-frequency current.

Modulation is accomplished in this transmitter by means of two vacuum tubes, which are termed modulator tubes when used for this function. In addition to the two modulator tubes, a third tube is used which functions as a speech amplifier. The circuit diagram and principles of operation of this transmitter for telephony will be taken up in a later Section.

40. Appearance of Transmitter.—The general appearance of the transmitter is shown in Fig. 15. Doors are provided in the front panel for easy access to the loading coil, the plate coil, and the grid-condenser adjustments. Additional doors in the bottom part of the front panel give access to all fuses and terminal connections to the transmitter. All equipment which may require attention from time to time, such as the motor starter and motor-driven interrupter, are accessible from the right-hand side of the transmitter.

The compartment *a* contains all the tubes and may easily be entered through the screen door on the top of the set. The antenna connection is made to the binding post *b*. The plate voltage may be read directly on the plate voltmeter *c*, and the antenna current on the ammeter *d*. The change from telegraph to telephone transmission is made by means of the switch *e*. A similar switch *f* is used to control the power.

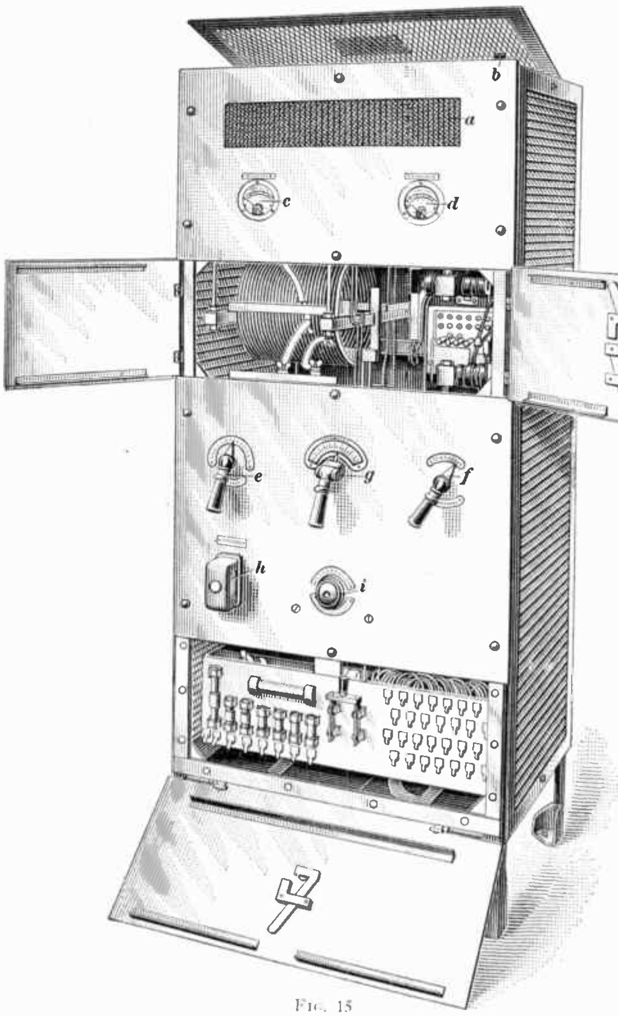


FIG. 15

The wave-length is regulated by means of the wave-change switch *g*. At *h* is shown the overload-protection relay, and at *i* is the voltage regulator.

HIGH-POWER VACUUM-TUBE TELEGRAPH TRANSMITTER FOR SHIP USE

41. There have been installed on a number of American battleships and on one of the largest transatlantic passenger ships, 5,000-watt vacuum-tube telegraph sets of the type shown in Fig. 16, which represents the installation of one of these sets on the Leviathan. This transmitter is designed to send continuous-wave telegraph signals on four different wave-lengths. A rotary wave-change switch operated by hand with an automobile steering wheel permits of almost instantaneous change to any one of four wave-lengths, 1,800, 2,100 2,400, or 2,500 meters. The oscillating circuit of this transmitter is substantially the same as that used for the tube-attachment set. Power is supplied by the ship's direct-current generator to a 10-kilowatt motor-generator set, which delivers 500-cycle alternating current to the transmitter. This is stepped up to the proper voltage of 8,500 and applied to the plates of the high-power oscillating tubes in such a manner that each tube functions alternately as in the so-called self-rectifying type of transmitter, as indicated in Fig. 13. On one half-cycle of the alternating current, the plate of tube No. 1 is positive with respect to the filament, and radio-frequency oscillations are set up through this tube. On the next half-cycle, the plate of this tube is negative to the filament and no current passes. At this time, however, the plate of tube No. 2 is positive to its filament, and this tube begins to function as an oscillator. Thus radio energy is delivered to the antenna in pulses twice per cycle of the power supply, or in other words 1,000 times a second. This gives a 1,000 cycle note in a crystal receiver. In an oscillating receiver circuit a beat note is produced which can be heard over much greater distances than with the crystal receiver, since all the advantages of continuous-wave reception are obtained.

42. The plates of these high-power tubes are water-cooled. In the past, the manufacture of high-power tubes has been limited by the fact that the heat generated in the plate could not be dissipated fast enough to prevent the tube from being destroyed. This heat is caused by the force with which the electrons traveling at approximately 1,700 miles a second strike the plate—just as hammer blows will heat a piece of

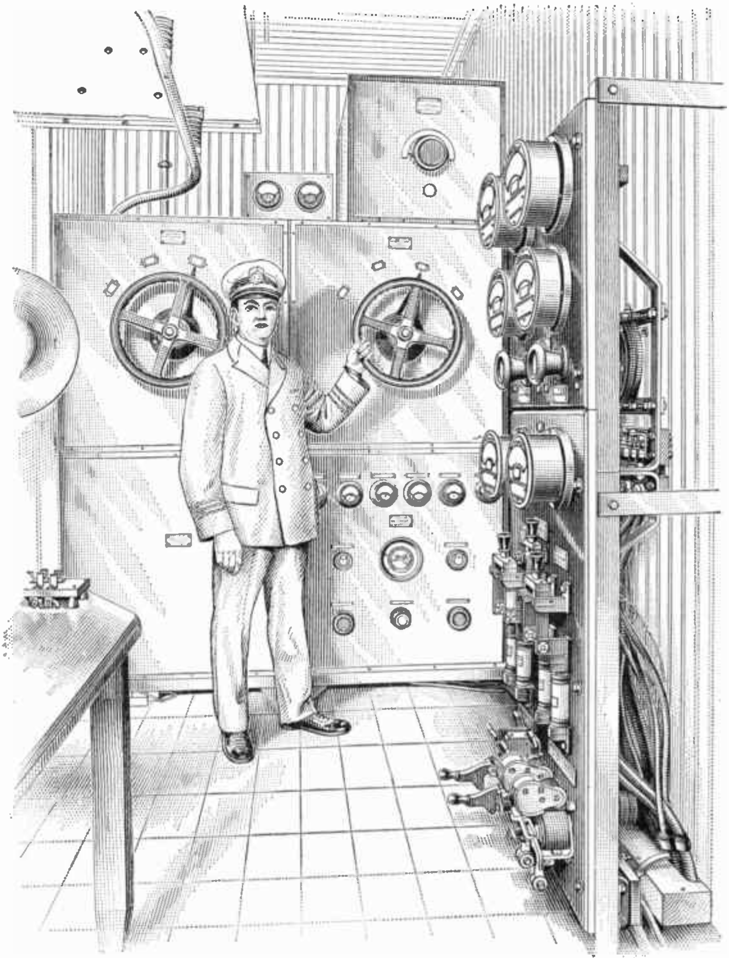


Fig. 16

iron. This heat must be carried off or a vacuum tube will burn out. In vacuum tubes of the usual construction 50 watts of power is all that can be safely dissipated per square inch of plate surface. The plates of the vacuum tubes used in the transmitters previously described, as well as in all such transmitters used in the modern broadcasting stations, become very hot during operation on full power. The invention of the copper-to-glass seal made it possible to construct the tube so that water is made to circulate around the outside of the plate and in this way it is possible to carry off 28 times as much heat as could formerly be dissipated. With this type of water-cooled tube it is possible to dissipate 1,400 watts per square inch of plate surface.

Since these tubes will burn out if the water supply is cut off during operation, they are protected by a pressure indicator that breaks the circuit and cuts off the current supply when the water pressure becomes too high or too low.

It is necessary, as the plates of these tubes operate at 8,500 volts, to feed the water to them through an insulated hose, about 10 feet in length, which is held in two coils. To prevent excessive current leakage through the circulating water, it must have a very high resistance so as to be relatively non-conducting. For this reason only clean fresh water can be used for circulating purposes. A small motor-driven pump forces this relatively pure water, stored in a 20-gallon tank, through the hose, coils, and water-jackets of the vacuum tubes. Salt water is kept flowing through a copper coil in this tank for cooling the circulating water.

AIRCRAFT RADIO-TELEGRAPH TRANSMITTERS

43. The earlier types of aircraft transmitters were mostly of the damped-wave type, having wind-driven generators as a source of primary power. The more modern transmitters are of the vacuum-tube type, using for the power supply a generator directly connected to the aircraft engine, with a storage battery floating across the supply as an emergency source of power in case the engine fails. The apparatus for aircraft purposes is constructed along lines convenient for installation in the fuselage of the plane, and is mounted conveniently in front of the pilot or observer. It is constructed with especial view to light weight, which is of great importance in aircraft work. The antenna is usually of the weighted trailing-wire type, suspended from a fitting on one side of the machine close to the fuselage, and capable of being reeled in or out as necessary. The metal parts of the fuselage are connected electrically to the guy wires of the wings which serve as the counterpoise or ground system for the transmitter.

44. The vacuum-tube type transmitters may be used for either telegraph or telephone, as desired. The telephone is generally used, although telegraph is preferable for long-range communication, owing to the advantages obtained from continuous-wave transmission.

Short-range radio-telephone sets operate at distances up to 80 miles and are used for intercommunication between airplanes in formation and for communication between planes overhead and ground radio stations.

Long-range transmitters are usually equipped only for telegraph operation and are used by airplanes and dirigibles for overland distances up to 200 miles. For large dirigibles, equipment is provided for transmitting reliably over 600 miles.

COMPASS STATIONS

45. Shore Radio-Compass Stations.—Radio-compass stations have been established at the principal harbor and navigable river entrances on the coast line of the United States. In order to obtain the ship's position as she approaches a harbor, it is merely necessary for the ship to call the naval shore station and request a position report, following this call by the letter *V* for two minutes, at the end of which time the naval shore station will transmit to the ship its latitude and longitude. Each radio-compass station on shore consists of two or three receiving stations equipped with the direction-finding compass apparatus for taking bearings, and one transmitting and plotting station, which is connected by direct telephone wire to the two or more receiving compass stations. When a vessel calls for a bearing, the receiving compass stations each take the bearing and telegraph it immediately to the transmitting and plotting station, where the bearings are plotted on a chart, and the resultant position is then transmitted to the vessel by radio. The time consumed for the whole operation is less than 5 minutes. This method is used very extensively today, and is an improvement over the older method inasmuch as the actual plotting of the ship and determining of its latitude and longitude is done by the shore operators and not the operator of the ship.

The radio compass may be read accurately within one degree by an experienced operator, and is extremely valuable in locating the position of a vessel in thick or foggy weather. Prior to being used the compass has to be calibrated in order to correct for the constant errors in distortion of waves due to surrounding metallic objects.

46. Ship Radio-Compass Stations.—Instead of having the direction-finding compass, loop, and apparatus on the shore, it may be suitably located on the ship so that the captain or ship's navigating officer may obtain a bearing of the ship for himself by simply revolving the specially constructed and supported outside loop so as to obtain maximum signal strength from two or more definitely known transmitting stations. The United States lighthouse department has recently equipped a number of its important harbor lighthouses with automatically operated transmitters for this purpose, which are started in operation as soon as the weather becomes at all foggy. These transmitters are of the vacuum-tube type using interrupted continuous-wave transmission of certain fixed letters for each transmitter so that each station can be readily distinguished. These transmitters have a reliable range of about 25 miles and operate on a wave-length of 1,000 meters.

47. Directive Radio Beacon.—The directional feature of a loop, or coil antenna, may be utilized in the transmission as well as in the reception of radio signals. When used as a transmitter, or radiator, of radio signals, it is found that receiving stations located in the plane of the loop receive the signals with maximum intensity. On the other hand, the stations that are located at points at right angles to the loop will receive very weak signals or none at all.

The intensity of the signals received at various points equidistant from a transmitting station using a loop antenna may be compared to the length of lines from a common point on the circumference of a circle to other points on the circumference as indicated in Fig. 17. The loop antenna *a* transmits the strongest signals in the directions *a b* and *a c*. The signals in the directions *a d* and *a e* will be the weakest. If a receiving set is located at the point *c*, the intensity of the received signal will correspond with the length of the line $a c_1$. When the receiving set is moved to point *f*, the received signal will be somewhat weaker, and will compare with the signal received at *c* just as the line $a f_1$ compares with $a c_1$. The signal will decrease in intensity as the receiving set is moved to the points *g* and *h*, and finally reaches its minimum value when the set is at point *d*. The signal will increase in amplitude as the receiving set is moved in an arc from the point *d* to *b*.

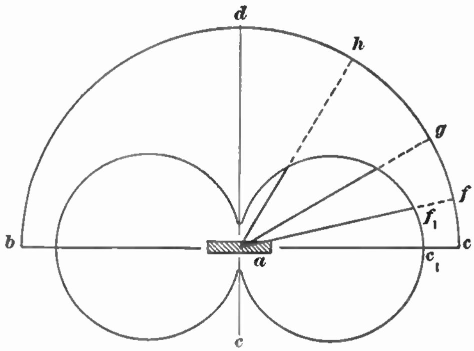


FIG. 17

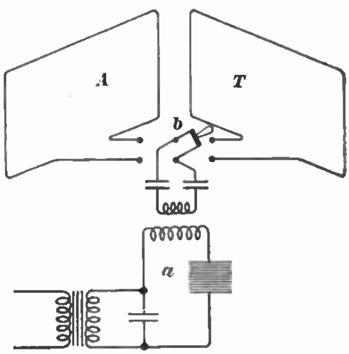


FIG. 18

48. It has been proved experimentally that two-coil antennas alternately transmitting signals may be used to guide a ship or an airplane to the desired location. The circuit arrangement for the loops is shown in Fig. 18. The oscillating circuit *a* includes a condenser, a quenched-spark gap, and an inductance coil. The energy from this closed oscillating circuit may be transferred inductively to either one of the two loops by operating the double-pole double-throw switch *b*. When the switch is thrown to the left, the left-hand loop is active; when the switch is thrown to the right, the right-hand loop radiates the energy. By means of apparatus, not shown, different letters are transmitted on each loop. For example, the left-hand loop may transmit the letter *A*, while the right-hand loop the letter *T*, as indicated in the figure.

49. The two coil antennas *A* and *T* shown crossed in the lower portion of Fig. 19 are made to transmit alternately the letters *A* and *T*. The airplane *a* moving to the right will first come to position *1*, where the signals from the loop antenna *A* will be much louder than that from the antenna *T*. The relative intensities of the two signals are indicated approximately by the number of cross-lines on the two beams. The beams having the greater number of cross-lines indicate the louder signal. In position *2*, the signal from the antenna *A* only, will be heard. In this position the plane is exactly at right-angles to the antenna *T* and hence no signals from that antenna will be received.

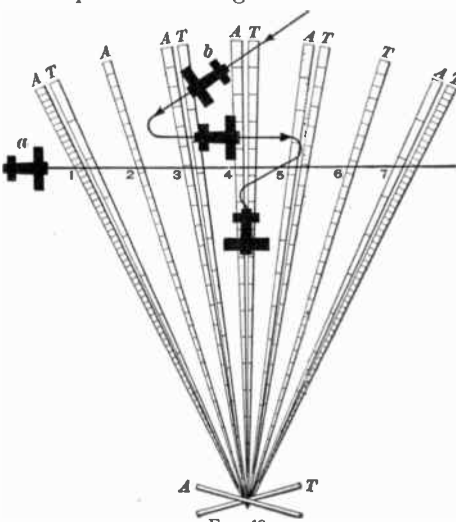


Fig. 19

As the plane *a* reaches position *3*, signals from the antenna *A* will grow weaker, and signals from the antenna *T* will become audible. In position *4*, the signals from the two antennas will be of equal intensity. From positions *5* to *6* the intensity of the *A* signals is decreased and of the *T* signals is increased. At position *6* the *A* signals are not received. At position *7* both the *A* and the *T* signals are increased in loudness.

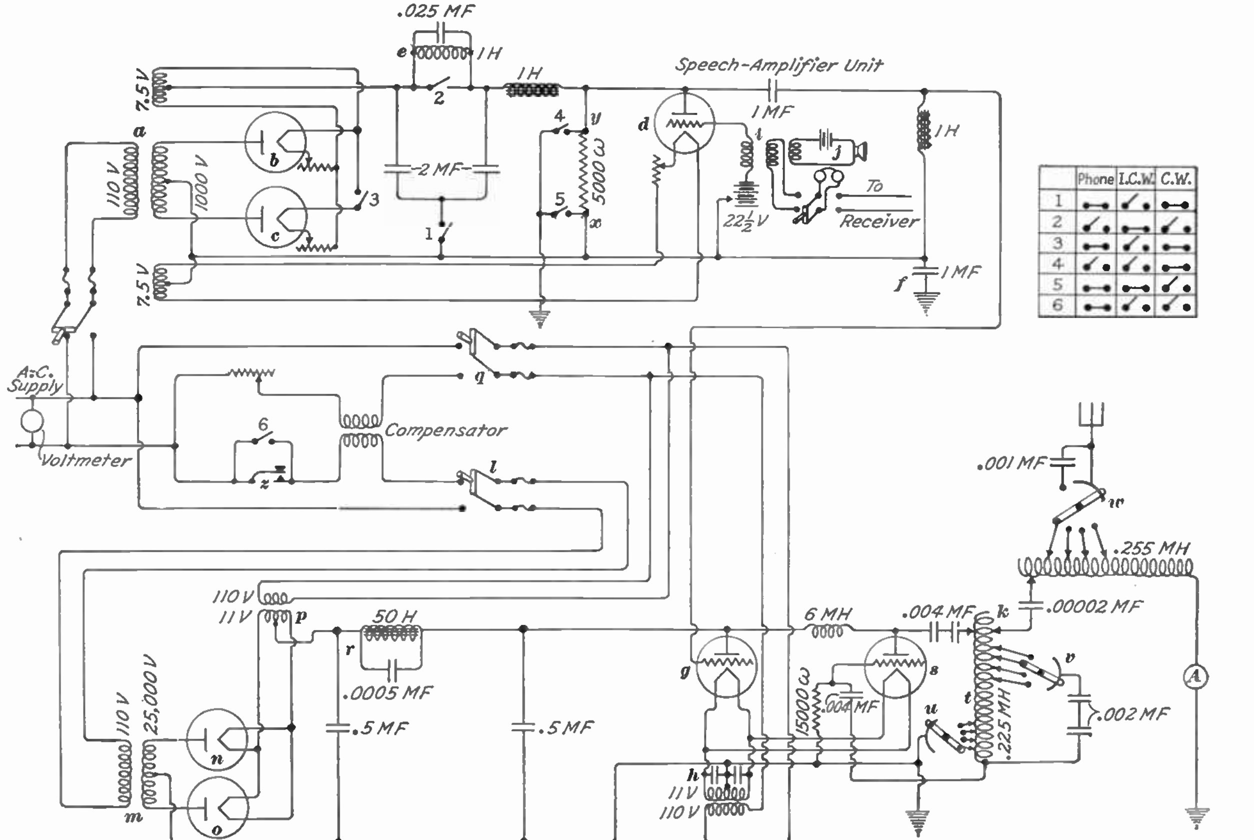
The airplane *b* may easily find its direction of flight toward its landing by following the signals from the two coil antennas. When the intensity of the signals from each of the two antennas is the same, the airplane may continue in its flight in a straight line toward the transmitting station. Deviations from its true course due to wind may be corrected immediately.

MARINE TUBE SET FOR CONTINUOUS-WAVE, INTERRUPTED CONTINUOUS-WAVE, AND TELEPHONE OPERATION

50. A circuit diagram of a 750-watt tube set that may be used for continuous-wave, interrupted continuous-wave, or telephone transmission is shown in Fig. 20. The main feature of this system is the speech-amplifier unit, which makes such transmission possible.

This set employs the same type of motor-generator set and automatic starter described in a preceding Section. The type of power transformer *a* used in the speech-amplifier circuit is one that is designed for 500-cycle energy. The primary winding designed for a 110-volt circuit and the transformer has three secondary windings. One secondary winding supplies a 1,000-volt potential for the plates of the two rectifier tubes *b* and *c*, that is, 500 volts to each tube, the second winding supplies the filament current for the rectifiers (this winding is insulated for 1,100 volts); and the third winding supplies the filament current for the 5-watt speech-amplifier tube *d*.

51. Rectifier for Speech Amplifier.—The rectifier tubes *b* and *c*, Fig. 20, are of the UV-216 type and they are rated for 20-watts output. Two are used to give full-wave rectification. A 5-ohm rheostat is put in series with the filament of each of these tubes to give the proper control. This is necessary so that it will be possible to prolong the life of the tubes by cutting down the filament current to get normal efficiency of operation with minimum amount of filament current.


.025 MF
e
1 H
1 H
Speech-Amplifier Unit
1 MF
7.5 V
a
110 V
1000 V
b
c
2
3
-2 MF-
1
4
5
y
x
5000 ω
d
i
j
22½ V
To
Receiver
1 H
1 MF
f
7.5 V
Phone
I.C.W.
C.W.
1
2
3
4
5
6
A.C. Supply
Voltmeter
q
6
z
Compensator
l
.001 MF
w
.255 MH
110 V
11 V
p
50 H
r
.0005 MF
.5 MF
.5 MF
6 MH
.004 MF
k
.00002 MF
g
s
15000 ω
.004 MF
v
u
t
.225 MH
.002 MF
A
110 V
25,000 V
n
o
m
h
11 V
110 V
Fig. 20

52. Filter.—The lead to supply the plate voltage for the speech-amplifier tube *d* is tapped off the mid-point of the kenotron-filament winding, Fig. 20, but before it gets to the plate it passes through a refining process that irons out the 1,000-cycle ripple that predominates at the start. If only one rectifier tube were used, but one side of the 500-cycle wave would be rectified and there would be a 500-cycle ripple, but when two kenotrons are used, both sides of the wave are rectified (full-wave rectification), and there are two ripples per cycle which means, in this case, a 1,000-cycle ripple. The first series circuit that it comes to is a 1,000-cycle trap *e*, which is an application of the anti-resonant wave trap. It consists of a 1-henry reactor in parallel with a .025-microfarad condenser, and since the combination tunes to a frequency of 1,000 cycles (300,000 meters) it will eliminate this frequency, since it is the property of a parallel circuit tuned to a given frequency to offer extremely high impedance to that frequency when connected in series with a circuit carrying current of that frequency. Thus the trap offers an extremely high impedance to the 1,000-cycle ripple. On either side of the trap a 2-microfarad condenser is connected from the positive to the negative side of the rectified supply from the kenotrons. It is to be noted that the negative side is kept free from ground as far as direct current and speech frequencies are concerned, the only ground connection being a radio-frequency ground through a 1-microfarad condenser *f*. A radio-frequency choke of 1 henry is added between the 1,000-cycle trap and the plate of the speech-amplifier tube *d*.

53. Speech-Amplifier Tube.—The speech-amplifier tube *d*, Fig. 20, is the UV-202 and is rated at 5-watts output. There is, after the filtering, a pure direct-current supply to the plate of this tube. It is so well filtered from 1,000 cycles that it can be called a direct current. The value of the direct-current voltage is equal to the voltage that is applied to the plates of the two kenotron tubes, that is, 500 volts, less the loss or drop in voltage due to the plate-to-filament resistance of each kenotron tube and choke-coil resistance. The value of the plate voltage to the UV-202 tube in this case is equal to 400 volts. A lead is run from the plate of tube *d* through a blocking condenser to the grid of the modulator tube *g*. which is a UV-206, and is rated at 1-kilowatt output. The transformer *h* supplies the filament current for tube *g*. The filament of the speech-amplifier tube *d* is supplied with current from that winding of the power transformer *a* set aside for this purpose. The mid-point of this filament winding is connected to the common negative. The grid of tube *d* is connected to one side of the secondary winding of a microphone transformer *i*. From the other side of this winding a connection is made to the negative side of a 22-volt bias battery. The negative bias necessary for this tube functioning under these conditions is found to be best somewhere between 6 and 9 volts. The positive side of the bias battery is connected to the common negative. which in turn is connected to the grid of the power-modulator tube through a 1-henry reactor.

54. Microphone Circuit.—The microphone circuit *j*, Fig. 20, is composed of a standard microphone and a 6-volt battery in series with the primary of the microphone transformer. There is a third winding on the microphone transformer which is called the *side-tone winding*. This permits the operator to check the operation of his microphone by inserting a pair of telephone receivers in series with this winding. The usual method is so to wire the circuits that it is possible to use the receivers in the receiving circuit during receiving and in the side-tone circuit during transmitting. This is an important feature, because often in the course of conversation the operator will allow the position of the microphone, relative to the voice waves emitted from his mouth, to change, so that he will be speaking into it at an angle. This will cause the microphone to operate inefficiently and it will be noticeable immediately if the receivers are connected in series with the side-tone winding.

Before describing the oscillatory circuit it might be well to mention that the function that each of the switches *1*, *2*, *3*, *4*, *5*, and *6* performs, is in the changing from continuous-wave to interrupted continuous-wave, or to phone transmission and will be described in detail later.

55. Oscillating Circuit.—The oscillatory circuit, Fig. 20, is of the modified Hartley type and the only coupling between it and the antenna circuit is through the medium of the .00002-microfarad condenser *k*, Fig. 20, connected from the high potential end of the closed-circuit inductance to the high-potential end of the antenna tuning inductance. The inherent advantage in this kind of circuit is that it is so loosely coupled to the antenna system that there will be no reaction on the closed, or *tank*, circuit from the antenna circuit due to changes in the constants of the latter circuit. This is an important point in the design of a transmitter for ship use, because when a ship gets out to sea there is more or less motion due to wind and sea and the tendency is for the antenna to undergo more violent swinging than antennas on shore. The result is that the ship antenna is constantly undergoing changes in capacity. With this kind of antenna circuit, the swinging of the antenna and subsequent changing of capacity will not change the frequency of the emitted wave, but will simply change the efficiency of energy transformation from the tank circuit to the antenna circuit as the antenna swings in and out of tune with the tank, and it will have to swing violently in order to cause a change in signal intensity noticeable at the receiving station.

56. Plate-Voltage Supply.—When the plate switch *l*, Fig. 20, is closed it puts 110 volts on the primary of the plate transformer *m*. The voltage across the secondary is 25,000 and since this winding is grounded at its mid-point, the voltage on the plates of each of the rectifier tubes is 12,500. The kenotrons *n* and *o* are of the UV-218 type and are rated at 2.5 kilowatts. The filament supply for these tubes is obtained by means of the step-down transformer *p*, the primary of which is connected across the leads from the filament switch *q*. The 11-volt side of the transformer *p* must be insulated for 10,000 volts as the positive lead from the rectified supply is tapped off the mid-point of this winding and is 10,000 volts above ground. In using this type of rectifier the rectified voltage to be expected is 80 per cent. of the alternating-current voltage applied to the plates of the rectifier tubes. The positive side of the rectified supply is connected to the plate of the modulator tube *g* through a 1,000-cycle trap *r* composed of a 50-henry choke coil shunted by a .0005-microfarad condenser. The plate of the oscillator tube *s* is connected to the plate of the modulator through a 6-millihenry choke coil, which prevents any radio frequency from getting back to the modulator tube. Two .5-microfarad condensers are connected across the plate supply, one on either side of the trap *r*. These are for the purpose of smoothing out the plate supply from the rectifier to the modulator and oscillator. These last two tubes are each of the UV-206 type and rated as 1-kilowatt pliotrons. Their filaments are heated by means of a filament transformer *h*, which is connected across the filament switch *q*.

The grid of the modulator tube *g* is connected to the output of the speech-amplifier tube *d*. The grid of the oscillator tube *s* is connected to ground through a 15,000-ohm grid-leak resistance, which supplies the proper bias for this tube. This grid is also connected to the oscillatory circuit through the .004-microfarad blocking condenser. This condenser passes radio frequency but will not pass direct current so all the direct-current component of the grid current is forced through the grid-leak resistance. This current through this grid-leak resistance causes a voltage drop and this drop in potential is in such a direction that the grid is made negative with respect to ground. The amount that it is held negative during operation is determined by the value of the grid current and the value of the resistance in this circuit. A resistance of 15,000 ohms is about right for efficient operation.

57. The plate of the oscillator tube *s*, Fig. 20, is connected to the oscillatory circuit through the two .004-microfarad plate blocking condensers, which prevent the high-voltage plate supply from being applied to the tank inductance *t* with subsequent short-circuiting of the plate supply. These condensers, however, offer very little resistance to radio frequency. The ground connection to the tank inductance is made through the section *u* of the wave-change switch. The voltage between this ground connection and the grid end of the inductance is the grid-excitation voltage, and therefore as the wave-length is increased and the total amount of inductance is also increased, it is necessary to tap the ground connection on the inductance at a point farther away from the grid in order to keep the ratio of grid turns to plate turns constant and of the proper amount to obtain the correct grid excitation. The two .002-microfarad condensers in series are called *loading condensers,* since they increase the wave-length. One side of these condensers is connected to the grid end of the tank inductance and the other side is connected to the coil through section *v* of the wave-change switch. The point on the coil where this connection is made determines the wave-length, and the greater the number of turns that the condensers shunt, the greater will be the wave-length. The only coupling to the antenna circuit is through the .00002-microfarad coupling condenser *k*, which is connected from the high side of the tank inductance to the high side of the antenna inductance.

The low side of the antenna inductance is connected to the ground through a (0-20) radio-frequency ammeter, which shows the radiation. The antenna is connected to the high side of the inductance through the section *w* of the wave-change switch and for the lowest wave-length a .001-microfarad condenser is connected in series with the antenna. There are four wave-lengths available; namely, 450, 600, 700, and 800 meters. The changing from one wave-length to another is accomplished by means of a gang switch with the three sections *u, v, w.*

58. Functioning of Circuit for Telephone Work.—For telephone work the following conditions of the switches obtain as shown by the chart on the right-hand side of Fig. 20: *1* is closed, *2* is open, *3* is closed, *4* is open, *5* is closed, and *6* is closed. The bias on the grid of the modulator tube *g* is adjusted by means of the 5,000-ohm resistance in the speech-amplifier circuit. A good quality of speech is already coming from the output of the speech amplifier and in order to put this good quality on the air it is necessary to have the modulator grid biased by the proper amount. Now, if there is 300 volts on the plate of the speech-amplifier tube *d*, then, since the 5,000 ohms is connected directly across the direct-current supply, the point *x* is negative and the point *y* is at plus 300 volts. Since the switch *5* is closed to ground and since the mid-point of the modulator filament is at ground potential, the switch *5* and the mid-point of the modulator filament are the same electrically, and, therefore, electrically speaking, it may be assumed that switch *5* is the mid-point of the modulator filament. Also since point *x* is connected to the modulator grid it can be assumed that it is the modulator grid. Therefore, if the pointer of the 5,000-ohm potentiometer, which is connected to the switch *5* is at the point *x*, the switch *5* and the point *x* would be at the same potential, thus the modulator grid would be at the same potential as the filament and it would be the condition for zero grid. Now, if the pointer of the potentiometer is moved to a point on the resistance above point *x* where the potential was plus 10 volts, for instance, the ground or filament would be at a point 10 volts higher than the grid, or, saying the same thing in other words, the grid is at a potential of 10 volts negative with respect to the filament. Thus a 10-volt negative bias has been placed on the grid of the modulator tube, which bias could continue to a negative potential of 300 volts, but this would be unnecessary because the tube would have blocked with a bias far less than that. One of the advantages of this circuit is that the modulator bias may be adjusted while the tube is in operation and thus the quality of the signals can be brought to the finest possible point.

59. Interrupted Continuous-Wave Operation.—For interrupted-wave operation, the switch *1*, Fig. 20, is open, which cuts out the smoothing condensers; *2* is closed, which short-circuits the 1,000-cycle trap; *3* is open, which cuts out one kenotron and thus gives half-wave rectification with the accompanying 500-cycle ripple; *4* is open and *5* is closed, which gives the proper bias on the modulator tube for good modulation; *6* is open, which removes the short circuit across the key and allows the key *z* to function in keying the circuit. Thus, with the filter condensers and the 1,000-cycle trap out of the circuit and with one kenotron also cut out, the 500-cycle ripple from the rectifier goes through to the grid of the modulator tube, and the high-frequency energy being radiated when the key is closed is modulated by this 500-cycle note.

60. Continuous-Wave Operation.—For continuous-wave transmission, all the speech-amplifier switches, Fig. 20, are back to the position they had for telephone transmission with the exception of *4*, *5*, and *6*. The switch *4* is closed and the switch *5* is open, thus throwing the grid of the modulator tube so far negative that the tube blocks and refuses to function, the result being that a pure unmodulated, or continuous, wave is emitted. The switch *6* is open, thus allowing the key to function.

All of the switching in the speech-amplifier circuit is taken care of by a gang switch with six elements, an element for each one of the six switches. There are three positions of the gang switch; namely, continuous wave, interrupted-continuous wave, and telephone.

61. Compensator.—If there were no arrangement made to compensate for the drop in primary voltage when the key was pressed, the filaments, being connected to the same primary supply, would go down way below normal every time the key was pressed and the tubes would not function properly. Conversely, if the filament voltage was adjusted with the key down, when the key was raised and the primary voltage went up, the filaments would also go up and would burn at a voltage much higher than normal. This latter condition would greatly decrease the life of the filaments, and tubes would not give anywhere near their rated number of hours of service. Compensation is accomplished in this circuit by means of a series transformer, Fig. 20, one side of which is in series with one side of the primary supply to the plate and the other side of the transformer is connected in series with the primary supply to the filament. These windings are so connected that when the key is pressed and current passes in the primary circuit to the plate transformer, this current sets up a magnetic field in the compensating transformer, which is of sufficient strength and direction to boost the current in the primary supply to the filament transformers and thus keep the filaments burning at normal voltage when the key is down.

RADIO-TELEPHONE TRANSMITTERS

PRINCIPLES OF RADIO TELEPHONY

TELEPHONE SERVICE IN RADIO COMMUNICATION

1. **Radio Telephone and Radio Telegraph.**—The radio telephone supplements the radio telegraph in the same manner that the wire telephone supplements the wire telegraph. The advantages of the radio telephone over the radio telegraph are numerous. The radio telegraph requires an experienced operator who is familiar with the code, whereas the radio telephone does not. In the case of the radio telephone, therefore, the conversation can be carried on directly between the interested parties. Thus, the same factors that favor the wire telephone over the wire telegraph, operate in favor of the radio telephone over the radio telegraph.

2. **Radio Telephone and Wire Telephone.**—The radio telephone and the wire telephone bear the same relation to each other as the radio telegraph and the wire telegraph. Each has a definite and a distinct field of use. There is no antagonism; one aids the other. Thus, the radio telephone's accepted field of use is from ship to shore, from ship to ship, from airship to shore, and from airship to airship; also, between points on land that are separated by water or desert country, where it would be either impossible or extremely uneconomical to use wires. For instance, wire telephone communication between the United States and Europe would be very

impractical owing to the length of cable required and the difficulty of using capacity neutralizers and repeating amplifiers along the route. However, speech transmission by radio telephone has already been accomplished between the United States and England. Again, the radio telephone is found far more economical than the wire telephone between points that are separated by deserts and undeveloped country. The foregoing does not by any means imply that the radio telephone and the wire telephone are antagonistic, because the converse is true. They cooperate absolutely in their functioning, and go hand in hand in the development of the transmission of speech from one person to another. Take, for instance, the case where telephone conversations are carried on between persons in New York City and other persons on a ship hundreds of miles at sea, en route to Europe. The speech is transmitted via land line to the central radio station, where it is sent out by radio to the ship. Another instance of this close relationship between radio telephone and wire telephone, although their fields of use are distinctly different, is in the accomplishment of the transmission of speech from a person on land to another in an airship many miles distant. Here again the speech is carried by a land line to the central radio station and from there to the airship via radio.

The preceding discussion has only considered radio telephony from a standpoint of two-way conversation and therefore has not mentioned the most popular application of the radio telephone transmitter; namely, broadcasting.

RADIO-TELEPHONE APPARATUS AND BASIC CIRCUITS

ELEMENTARY RADIO-TELEPHONE TRANSMITTER

3. Elementary Circuit.—To transmit speech by radio it is necessary to have a source of radio-frequency energy and a means of varying this energy in accordance with the variations in speech frequency. Controlling the radio-frequency energy in this manner is known as *modulation*.

A simple telephone transmitter is shown in Fig. 1. It consists essentially of an antenna *a*, a variable capacity *b*, an inductance coil *c*, a source of radio-frequency energy *d*, a microphone *e*, and the ground *f*. The microphone *e* may be of the ordinary carbon-granule type and since a clear understanding of its functioning is necessary in order to understand better the facts that are to follow, a description of the construction and functioning of this piece of apparatus will be considered at this point, in detail.

4. **Microphone.**—In Fig. 2 is shown a cross-sectional view of the carbon-granule type of microphone. This diagram gives

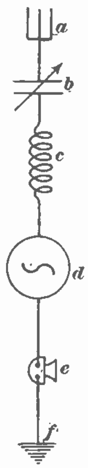


FIG. 1

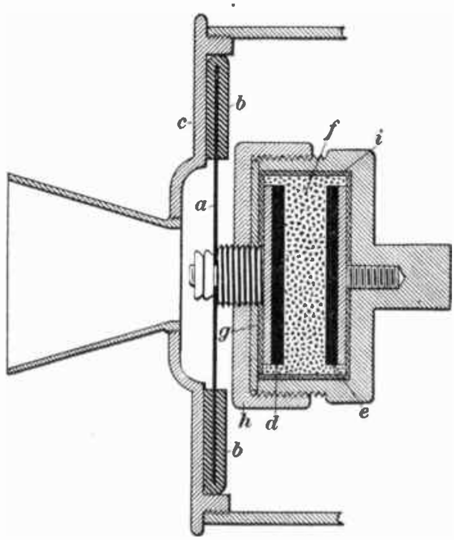


FIG. 2

a good idea of the construction of the microphone when stripped of details. The elastic diaphragm *a* is mounted on the rubber ring support *b*, which in turn is held against the metal frame of the microphone case *c*. The diaphragm is mechanically connected to a carbon block *d*, which is placed opposite a similar carbon block *e*. The chamber between the carbon blocks is filled with small carbon granules *f*. This chamber is sealed by means of the mica washer *g* and the insulating nut *h*. The wall of the chamber containing the carbon granules is covered with a strip of paper *i*. The two carbon blocks *d* and *e* are the electrical terminals of the microphone.

If an electromotive force is applied to the two terminals of the microphone a current will pass through the carbon granules. If the source is of constant polarity (direct current) the current will be unidirectional. If the source is of constantly changing polarity (alternating current) the current will be first in one direction and then in the other. The value of the current will depend on the potential applied and the resistance of the carbon granules. As long as the diaphragm remains in one position and the potential is constant the current will be constant, but it is a property of these carbon granules in the microphone to vary in resistance as the mechanical pressure exerted on them is varied. As the pressure is increased (an inward movement of the diaphragm) the resistance is decreased and as the pressure is decreased (an outward movement of the diaphragm), the resistance is increased. Hence, the current through the microphone is increased or decreased.

5. When someone is speaking into the microphone illustrated in Fig. 2, diaphragm *a* vibrates in synchronism with the frequency of the sound waves produced by the voice. Thus, the resistance varies in synchronism with the voice frequencies and it follows that the current passing through the carbon granules within the microphone, varies in a similar manner. The type of microphone just described is very sensitive to changes of pressure on the diaphragm. The current-carrying capacity of such a device is very small owing to the fact that a limit is soon reached where arcing occurs between granules, the contact points of which become red-hot, and the microphone becomes useless. The average resistance of a unit of this type is between 50 and 100 ohms. The current-carrying capacity is about .1 ampere. Thus the power capacity is a maximum of $.1^2 \times 100$, or 1 watt. There are some special low-resistance microphones (10 to 20 ohms) that have a current-carrying capacity of .5 ampere and a maximum power capacity of $.5^2 \times 20$, or 5 watts.

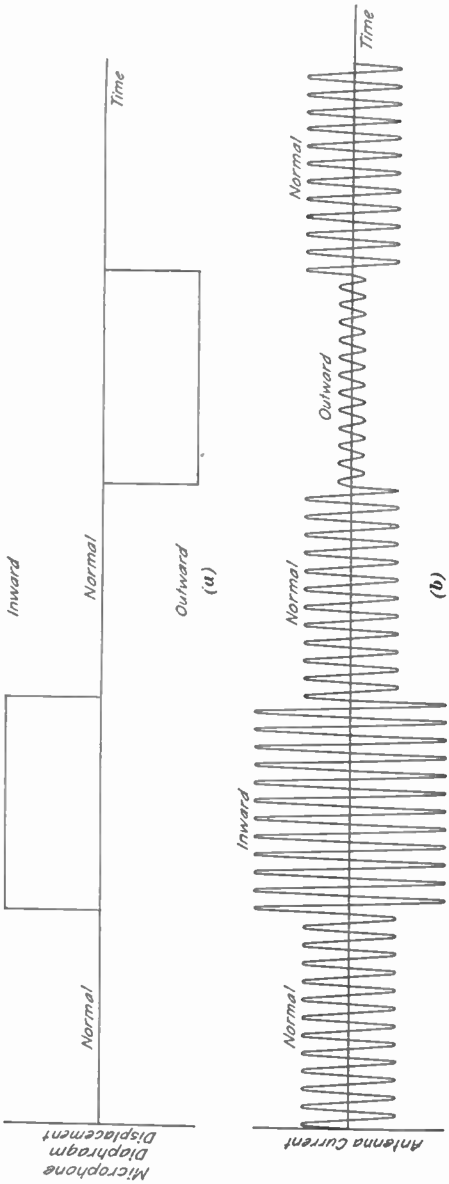


FIG. 3

6. Effect of Microphone on Radio-Frequency Currents. When the microphone *e*, Fig. 1, is not being spoken into, the diaphragm remains stationary and exerts a constant pressure on the carbon granules, the resistance of which, therefore, remains constant and the radio-frequency current in the antenna circuit is of constant amplitude as shown in Fig. 3. If the diaphragm of the microphone is depressed inwards, as indicated in view (*a*), the pressure on the carbon granules increases, the resistance decreases, and the amplitude of the antenna current, view (*b*), increases and remains constant at this value as long as the diaphragm is maintained in that position. When the diaphragm is released the resistance will return to normal and the antenna current also will return to its normal value. Again, if the diaphragm is pulled outwards, the pressure decreases, the resistance of the carbon granules increases and the antenna current subsequently decreases and remains at this lower value as long as the diaphragm is held in the outward position. Then, of course, when the diaphragm is released, the resistance will return to normal and the antenna current will again reach its normal value.

7. Let it be assumed that a 1,000-cycle tuning fork is set vibrating and placed in front of the microphone. Owing to

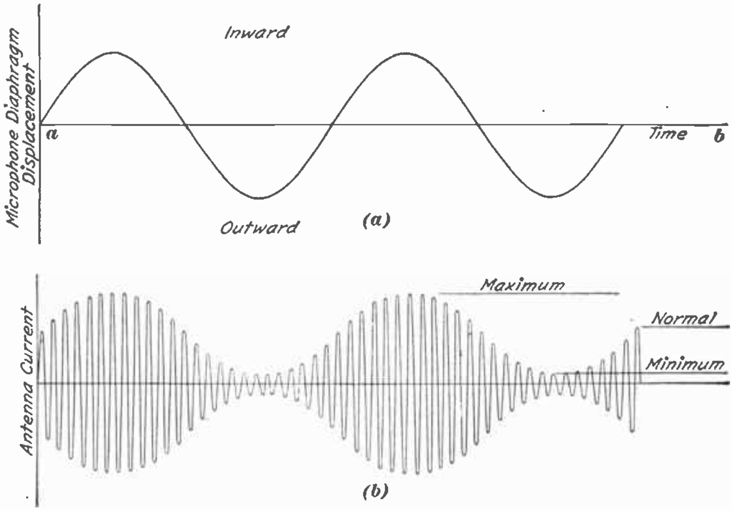


FIG. 4

the sound waves from the tuning fork, the diaphragm of the microphone will vibrate at a frequency of 1,000 cycles. In Fig. 4, if the line *a b*, view (*a*), represents the normal position of the microphone diaphragm when idle, then the sine curve superimposed on the straight line represents the action of the diaphragm when the tuning fork is placed in front of the mouthpiece. Thus, the diaphragm attains its maximum inward and outward positions 1,000 times per second and the resistance of the carbon granules varies accordingly. The antenna current, as indicated in view (*b*), will go from maximum to minimum and back to maximum again 1,000 times per second and the radiated energy will vary accordingly.

The radio frequency is the *carrier frequency*. The radio-frequency current is the *carrier current*. The frequency of the microphone diaphragm, which in this case is 1,000 cycles per second, is the *modulating frequency*.

From the foregoing it follows that it is possible to modulate the carrier current by the voice and thus transmit speech. Instead of placing the tuning fork in front of the microphone one may talk into the mouth piece, which will vibrate in accordance with the complex air vibrations produced by speaking.

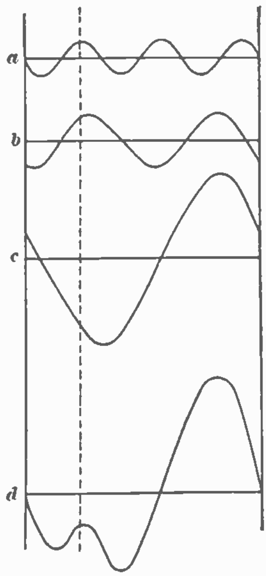


FIG. 5

8. Harmonics.—The diaphragm of a telephone transmitter should respond faithfully to all the different frequencies impressed on it. Suppose that instead of one tuning fork three of them are brought near the transmitter, each differing in pitch, or frequency, and loudness. The curve *a*, Fig. 5, represents the pitch and loudness of one tuning fork; the curve *b* represents the sound produced by another tuning fork, which, as may be seen, is of a lower frequency but of a higher amplitude than curve *a*; the curve *c* represents the sound produced by still another tuning fork, this sound differing from the preceding two in both pitch and loudness. Three different forces are acting on the transmitter and each one of them has an effect on the diaphragm. Of course the loudest tone *c* has the greatest effect, but the other two are not neglected. For example, at the instant represented by the dotted line, the curves *a* and *b* show a decided tendency to move the diaphragm inwards; the curve *c*, on the other hand, shows a much stronger tendency to move the diaphragm in the opposite direction, or outwards. The effect on the diaphragm is represented in the curve *d*. At the instant represented by the dotted line when the curves *a* and *b* act in opposition to curve *c*, the influence on the diaphragm, curve *d*, may be readily seen. The diaphragm, curve *d*, is bent outwards, by the curve *c*, but the loop in the curve *d* at this point indicates the effect of the curves *a* and *b*. The curve *d* is, as may be seen, the resultant of the component curves *a*, *b*, and *c*. If the diaphragm of the microphone vibrates in the fashion shown in curve *d*, it will satisfy each of the tuning forks and the sound heard at some distant receiver will be the same as that imposed on the transmitter.

9. In a complex wave such as that represented at *d*, Fig. 5, the predominating tone *c* is called the *fundamental tone*, and the other two, *a* and *b*, are the *overtones*, or *harmonics*. A harmonic may be two, three, or more times the frequency of the fundamental tone, and hence it is called a second harmonic, a third harmonic, etc.

When two waves of the same frequency similar to that at *c* pass through their maximum, zero, and minimum values at the same time they are considered as being *in phase*. When their corresponding maximum and minimum values do not occur at the same time even though both waves may be of the same frequency, the waves are considered as being *out of phase*. The difference in phase is usually expressed in degrees. One complete set of values from normal or zero to maximum in one direction, zero, maximum in the opposite direction back to zero, is given a value of 360 degrees.

10. All the complex vibrations of the microphone due to speech may be resolved into an infinite number of harmonic components of different frequencies and different amplitudes bearing certain phase relations to one another. Theoretically the number of these components is infinite, but practically, only those having a frequency of between 300 and 2,000 cycles per second have an amplitude great enough to be considered. The amplitude of the others is so small that they are negligible.

The following is a principle that is of very great importance in radio telephony as well as in wire telephony: As long as the amplitude of the harmonic components of the transmitting microphone diaphragm vibrations are reproduced in the receiving microphone diaphragm vibrations, bearing the same ratio to one another that they had at the start, without any reference whatever to phase relations, the speech that caused the vibrations of the transmitting microphone diaphragm will be faithfully reproduced in the receiver without any distortion.

SOURCES OF RADIO-FREQUENCY ENERGY

11. In order to transmit speech by radio it is necessary to have a source of radio-frequency current of constant amplitude (C. W.), and a system of modulation. Of the various sources of radio-frequency energy, the following have been most generally used for radio telephony: the alternator, the Poulsen arc, and the vacuum tube.

The vacuum tube may be used in many types of circuits to generate radio-frequency currents. A discussion of the fundamentals of the most important of the different types of oscillatory circuits follows. The various types are usually designated by the names of their inventors and fundamentally they are the same. The circuits that will be considered at this time are of the self-excited type. The fundamentals of all of the oscillatory circuits of this type are the vacuum tube; the power source (B battery); the load circuit (transmitting antenna); and a means of feeding power back to the grid circuit for its excitation.

MEISSNER CIRCUIT

12. The *Meissner circuit*, which is named after Dr. A. Meissner, of the Telefunken Company of Berlin, is shown in Fig. 6. The direct-current plate supply passes through the inductance *a*. The frequency of the oscillations generated by the tube is determined by the constants of the plate circuit; namely, the inductance of coil *a* and the capacity of condenser *b*.

The grid condenser and grid biasing resistance are shown at *c* and *d*, respectively. The former is of sufficiently high capacity to offer a low resistance to the passage of the radio-frequency currents that are generated by the tube and is therefore a *by-pass* for these currents. It also blocks off all direct current in the grid circuit at such a point that it is necessary for this direct current to pass through the biasing resistance, or grid leak *d*. There is a direct current in the grid circuit due to the passage of electrons from the filament to the grid just as there is direct current in the plate circuit due to the flow of electrons from the filament to the plate. Of course, the grid current is much smaller than the plate current. This grid current passes through the resistance *d* toward the grid. There is a drop in voltage across this resistance and the end near the grid is negative and the other end positive. Since the positive end of the biasing resistance is connected to the negative filament lead, the grid has a negative bias, the amount of which depends on the value of the biasing resistance and the grid current passing in the circuit. When a 250-watt tube, type UV-204 is used, the grid resistance might be 10,000 ohms and the grid current about 30 milliamperes; thus there would be a drop of 300 volts across the biasing resistance and the grid would be thrown 300 volts negative.

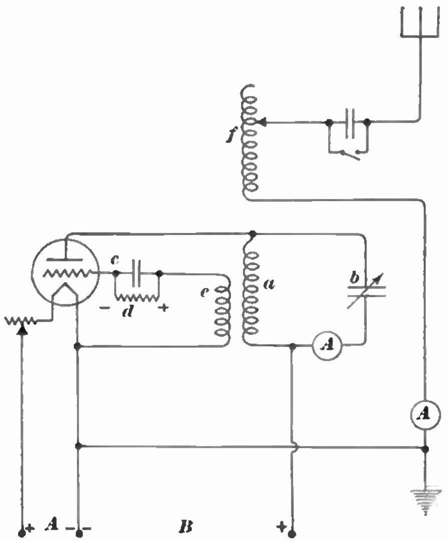


FIG. 6

13. The grid coil *e*, Fig. 6, is inductively coupled to the plate coil *a* and it is by this means that energy is fed back to the grid for its excitation. Care must be taken to have the proper phase relation in obtaining this feed-back for the grid excitation or the feed-back action may tend to block oscillations rather than maintain them. If either the grid coil or the plate coil is reversed from the position it should be in, the alternating-current feed-back to the grid will be in direct opposition, or 180 degrees out of phase with the pulsations in the plate circuit, and there will be a bucking action rather than a boosting action; thus oscillations will not be maintained. The grid circuit as shown is simply an untuned pick-up circuit but may be tuned to the frequency of the plate circuit by shunting a capacity of the proper value across the grid coil *e*. The antenna coil *f* is inductively coupled to the plate circuit and is tuned to the frequency of that circuit. This circuit is very flexible and by means of the coupling between the plate circuit and the antenna circuit, the transfer of power from any tube to the antenna circuit can be taken care of. The adjustment of the feed-back is also conveniently made and does not depend on the voltage drop across a reactance in the load circuit as in the case of the Hartley and Colpitts circuits, which are described later.

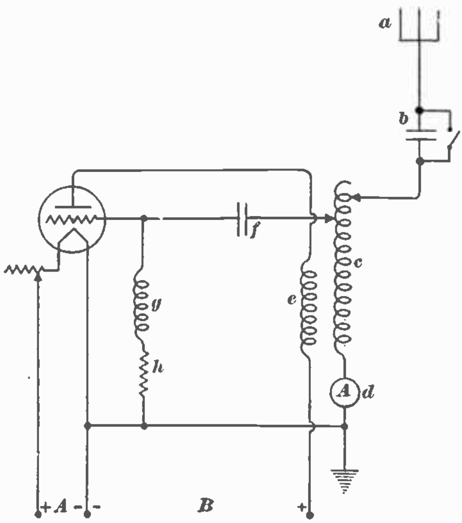


FIG. 7

TICKLER-COIL CIRCUITS

14. Inductive Plate Coupling.—The tickler-coil circuit with inductive plate coupling is shown in Fig. 7. The antenna circuit consists of the antenna *a*, the series condenser *b*, the inductance *c*, the ammeter *d*, and the ground. The plate is connected to the positive side of the high-voltage plate supply through the inductance *e*. The grid radio-frequency circuit is coupled to the antenna circuit through the condenser *f*. The grid-leak circuit is composed of the radio-frequency choke coil *g* and the grid biasing resistance *h*. The choke coil *g* keeps the radio-frequency currents out of the grid-leak circuit. Without this choke coil there is a loss of 20 watts in a 5,000-ohm grid leak when a 250-watt tube is used, which is 8 per cent. of the normal power. This loss is due to the passage of radio-frequency currents through this biasing resistance. When the choke coil *g* is used, the loss is decreased to .5 watt, which is .2 per cent. of 250 watts. The amount of grid excitation is determined by the capacity of condenser *f* and the point at which the grid is tapped on the coil *c*. The coupling between plate and grid due to the coil *e*, maintains the oscillatory condition. The constants of the antenna circuit determine the frequency of the oscillations generated by the tube.

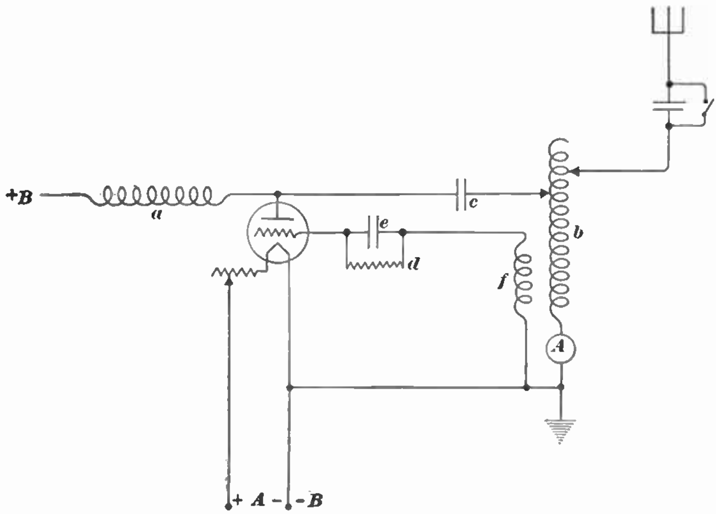


FIG. 8

15. Inductive Grid Coupling.—The tickler-coil circuit with inductive grid coupling is shown in Fig. 8. The antenna circuit shown here is the same as in the previous case and determines the frequency of the oscillations. The plate potential is supplied through the radio-frequency choke coil *a*.

The purpose of this coil is to isolate the radio-frequency current in the plate circuit from the high-potential current of the plate supply. The plate is connected to the antenna coil *b* through the blocking condenser *c*. The purpose of this condenser is to keep the inductance coil *b* from short-circuiting the direct-current plate source. The grid biasing resistance and grid condenser are shown at *d* and *e*, respectively, and function as previously described. The grid excitation is derived by means of the grid coupling coil *f*. The grid circuit as shown in the figure is an untuned pick-up circuit but may be tuned to the frequency of the antenna by shunting a capacity across the coil *f*. The last two circuits described are not so flexible as the Meissner circuit.

ARMSTRONG REVERSED FEED-BACK CIRCUIT

16. The Armstrong tuned-plate, or reversed feed-back circuit, which is named after its inventor, Mr. E. H. Armstrong,

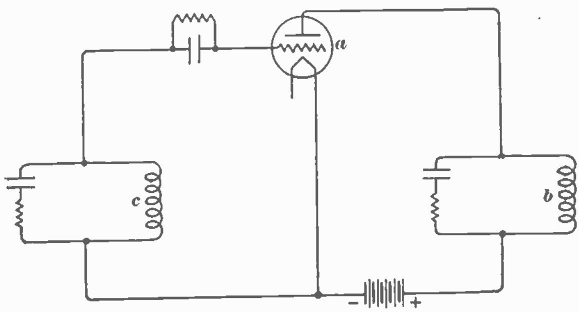


FIG. 9

is shown fundamentally in Fig. 9. In this circuit the oscillatory condition, which is due to the feed-back from the plate circuit to the grid circuit, is obtained by means of the small capacity coupling between the plate and the grid within the tube *a* itself. This small condenser is formed by the grid and plate electrodes. It is important to note that the plate and grid coils *b* and *c* are not inductively related but may be widely separated from each other. The only coupling between the plate and grid is the capacity coupling within the tube. The feed-back effect increases as the wave-length is shortened, and also depends on the value of the grid-plate capacity; so the action may often be improved and controlled by connecting a variable condenser of small capacity (.0001 microfarad) between the plate and the grid. Thus the principle of this circuit is different from any yet described.

Oscillations occur when the plate circuit is in tune with the grid circuit and the frequency of these oscillations depends

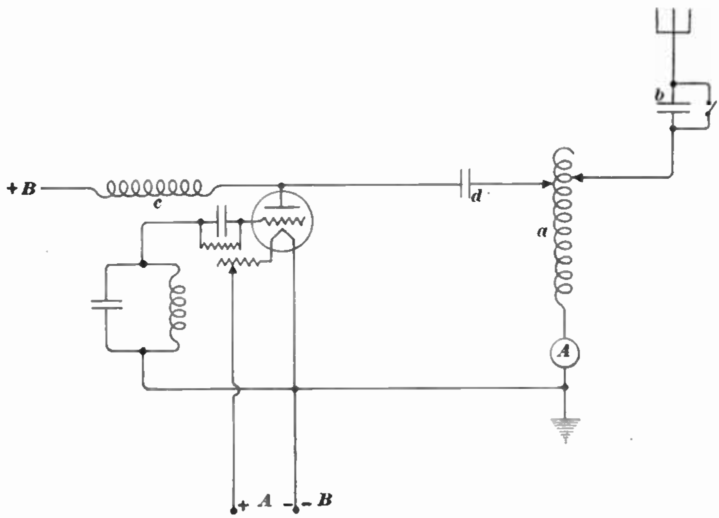


FIG. 10

mainly on the constants of the grid circuit but the constants of the plate circuit do have some effect on the generated oscillations. This is an important point, because by connecting the antenna to the plate circuit as shown in Fig. 10, the change in the antenna capacity due to swinging of the aerial will have a smaller effect on the frequency of the generated oscillations than in those circuits where the antenna circuit has a greater influence on the circuit whose constants determine the frequency of the oscillations generated. Thus, the constant-frequency advantage of the master-oscillator system is embodied to some extent in this circuit.

17. In Fig. 10 is shown the method of connections for transferring energy, generated by a tube in a circuit of the Armstrong reversed feed-back type, to an antenna. The tuned plate circuit shown in Fig. 9 is replaced in Fig. 10 by its equivalent, an antenna circuit of inductance *a*, series capacity *b*, and resistance. This circuit is tuned to the frequency of the grid circuit. The radio-frequency choke coil *c* functions as usual, to prevent the short-circuiting of the output circuit by the plate source; and the blocking condenser *d* functions, conversely, to prevent the short-circuiting of the plate source by the output circuit.

COLPITTS CIRCUIT

18. The Colpitts circuit, which is named after its inventor, Mr. E. H. Colpitts of the Western Electric Company, is shown fundamentally in Fig. 11. The frequency of the generated oscillations depends on the inductance *a* and the two capacities *b* and *c* in series. These elements together with the resistance *d* constitute the load circuit. The grid excitation is determined by the voltage drop across the condenser *c*, and therefore the smaller the condenser, the greater the voltage drop and the greater the grid excitation. The grid excitation varies with the power capacity of different tubes. If a 1-kilowatt tube were used in this circuit the values of inductance and capacity should be so chosen that, with 1 kilowatt dissipated in the circuit, the total reactive voltage (that between the points *e* and *f*) would be 7,500 volts. The proper grid excitation for this tube is 1,000 volts, so the proper values for the condensers *b* and *c* are determined by the relation $c \div b$ equals $6{,}500 \div 1{,}000$; then *c* equals 6.5 *b*. Thus when the grid condenser *c* is 6.5 times as large as the plate condenser *b*, the voltage drop across the grid condenser *c* is $1 \div 6.5$ of the voltage drop across the

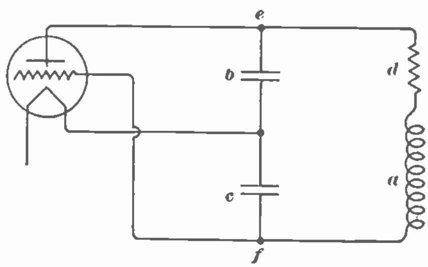


FIG. 11

plate condenser *b*, giving 1,000 volts across the grid condenser and 6,500 volts across the plate condenser and 7,500 volts across the two.

19. In Fig. 12 is shown the application of the Colpitts circuit to an antenna, with the addition of grid choke *a*, grid leak *b*, grid blocking condenser *c*, and plate choke *d*, which function as previously described. This circuit is the same as the fundamental circuit shown in Fig. 11 with the exception

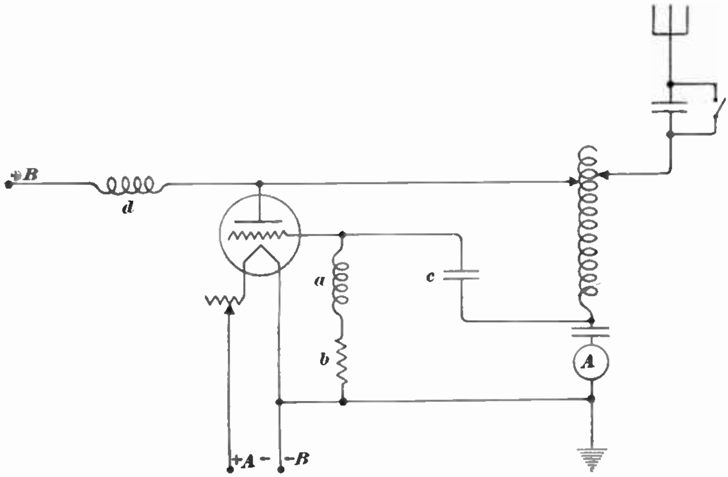


FIG. 12

that the plate capacity *b*, Fig. 11, has been replaced by the antenna, Fig. 12, which functions as a capacity. No plate blocking condenser is necessary in this circuit, since, owing to the load-circuit arrangement, there is no possibility that the plate supply will be short-circuited by the output circuit.

HARTLEY CIRCUIT

20. The Hartley circuit, which is named after its inventor, Mr. R. V. L. Hartley of the Western Electric Company, is shown in Fig. 13. The frequency of the oscillations generated depends on the constants of the load circuit. The grid excitation is obtained by means of the voltage drop between the points *a* and *b*. As is the case in the Colpitts circuit, the grid excitation depends on the voltage drop across a reactance in the load circuit, but in this case the reactive drop is across a coil, whereas in the Colpitts circuit the reactive drop is across a condenser. The greater the number of turns between the points *a* and *b* the greater the voltage drop and the greater the grid excitation. As in the previous case, if a 1-kilowatt tube, type UV-206, were used in this circuit, the total drop from the point *a* to the point *c* should be 7,500 volts and the drop from *a* to *b* 1,000 volts, thus leaving 6,500 volts from *b* to *c*.

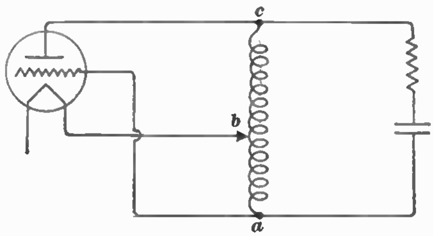


FIG. 13

In Fig. 14 is shown the application of the Hartley circuit to an antenna system. The fundamental change between the

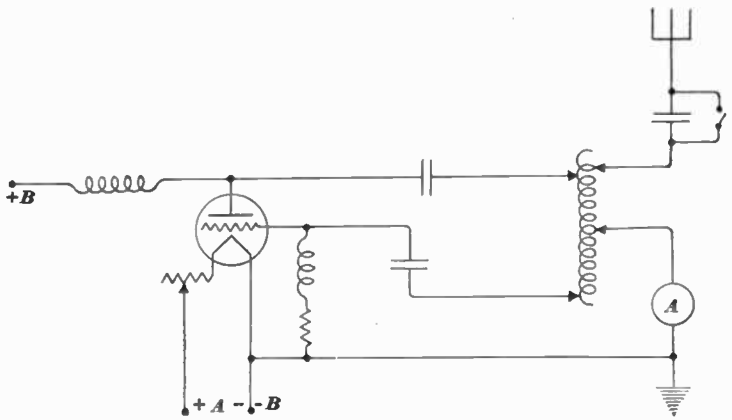


FIG. 14

circuit shown in Fig. 14 and the one in Fig. 13 is the replacing of the load-circuit lumped capacity and resistance by the antenna circuit, which has distributed capacity and resistance. This circuit, although not considered the best for direct application to an antenna system, has many useful applications both in transmitting and receiving, notably as a master-oscillator circuit for transmitting and as a local oscillator for heterodyne reception.

MASTER-OSCILLATOR CIRCUIT

21. All of the foregoing types of oscillatory circuits have been of the self-excited type; that is, they were of the type that supplied their own grid excitation. The master-oscillator system is a separately excited type of circuit. From an electrical viewpoint this type of circuit is superior to any of the self-excited type. It is far more flexible than the self-

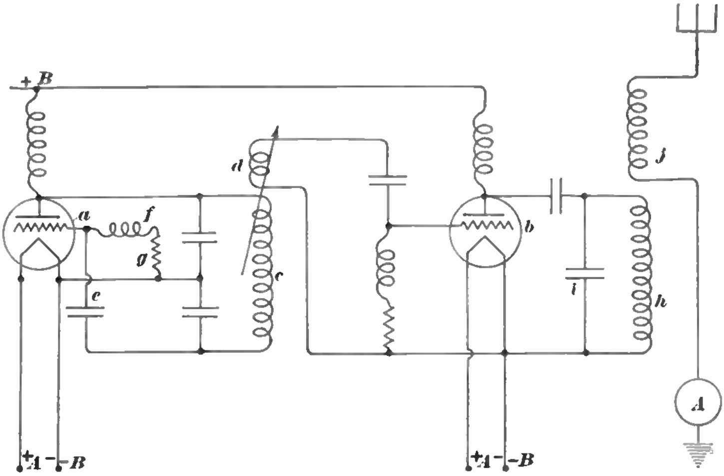


Fig. 15

excited type and is also less susceptible to frequency changes. This latter feature is of especial importance. The fundamental circuit shown in Fig. 15 is composed of two tubes. One is the master-oscillator tube *a* and the other the power-amplifier tube *b*. The constants of the master-oscillator circuit determine the frequency of the energy to be radiated from the antenna. The master-oscillator tube *a* simply has to be of sufficient size to supply the losses in its own oscillatory circuit and the losses in the grid circuit of the power-amplifier tube *b*. The losses in the grid circuit of the power tube *b* would probably be between 2 per cent. and 10 per cent. of the total capacity of the tube, hardly ever over 10 per cent. The oscillatory circuit for the master-oscillator tube *a* is of the Colpitts type, which has already been described. The grid circuit of the power-amplifier tube *b* instead of being coupled to its own output circuit as in the case of the self-excited types, is inductively coupled to the master-oscillator oscillatory-circuit inductance *c* through the grid coil *d*. The grid of the power-amplifier tube *b* is supplied with the proper amount of grid excitation by varying the coupling between the coils *c* and *d*. The grid-blocking condenser *e*, grid choke *f*, and biasing resistance *g*, function as previously described. The plate circuit of the power-amplifier tube is tuned by means of the inductance *h* and the condenser *i* to the frequency of the oscillations generated by the master-oscillator circuit. The antenna circuit is inductively coupled to the plate circuit of the power-amplifier tube *b* by means of the coupling coil *j*.

22. The adjustment of this system is simple. The master-oscillator circuit is first set at the frequency desired. The power-amplifier plate circuit is then tuned to resonance with the frequency of the master-oscillator circuit. The grid excitation of the power-amplifier tube *b*, Fig. 15, is adjusted for maximum efficiency. The antenna circuit is then tuned to the same frequency and its coupling to the power-amplifier circuit varied until maximum efficiency is obtained.

On ships at sea, during heavy storms, the ship rolls and the antenna swings from side to side and is constantly changing in capacity. If a type of circuit were used in which the antenna circuit was directly associated with that part of the circuit whose constants determined the frequency of the radiated energy, the frequency would change, owing to the change in antenna capacity, and the frequency of the radiated signals would vary in synchronism with the swinging of the antenna. This condition is unfavorable, because signals of this type are difficult to understand at the receiving station. They would be strong one minute and the next minute would be weak because of the change in wave-length and it would be impossible to vary the tuning of the receiver in synchronism with the variations in the frequency of the incoming signals. This condition is not only true of ship antennas but might also be true of shore-station antennas that are subjected to a strong wind. The master-oscillator system eliminates this condition. The frequency is fixed by the constants of the master-oscillator circuit and there is no reaction from the antenna. Therefore, the only thing that changes as the antenna capacity changes is the efficiency. As the antenna swings out of tune, the current in that circuit will decrease.

MODULATION

23. Methods Employed.—The function of the modulating system is to vary the radio-frequency output current in accordance with the low-frequency variations of the sounds to be transmitted. The different schemes of modulation operate principally by three fundamental methods, namely, variation of the resistance of the antenna circuit, of the grid voltage of the oscillator tube, and of the plate supply to the oscillator tube.

24. Variation of Resistance.—The first of these methods has already been touched on and is illustrated in Fig. 1. This method shows very clearly the fundamental operation of a radio-telephone transmitter, but as far as its practical application is concerned, it is obsolete where any power over 5 watts is used. Fair results can be obtained with it when the output of the transmitter is 5 watts or less, but the method is inherently a poor one.

25. Variation of Grid Voltage of Oscillator Tube.—The second method listed depends on the variation of the average grid voltage (biasing voltage) of the oscillator tube. In Fig. 16 is shown the application of this method of modulation when the Meissner type of oscillatory circuit is used. The functioning of this type of oscillatory circuit has already been described, so only the method of modulation will be considered here. The microphone circuit is composed of the microphone *a*, a 6-volt storage battery *b* or any 6-volt battery capable of supplying 200 or 300 milliamperes, and the primary of the microphone transformer *c*. The secondary of the microphone transformer takes the place of the grid biasing resistance and is connected across the grid condenser *d*. When the microphone *a* is spoken into, the resultant action is the varying of the grid biasing voltage in accordance with the variation in the microphone displacement. As mentioned before, the result desired is to have the amplitude of the antenna current vary exactly in accordance with the microphone displacement.

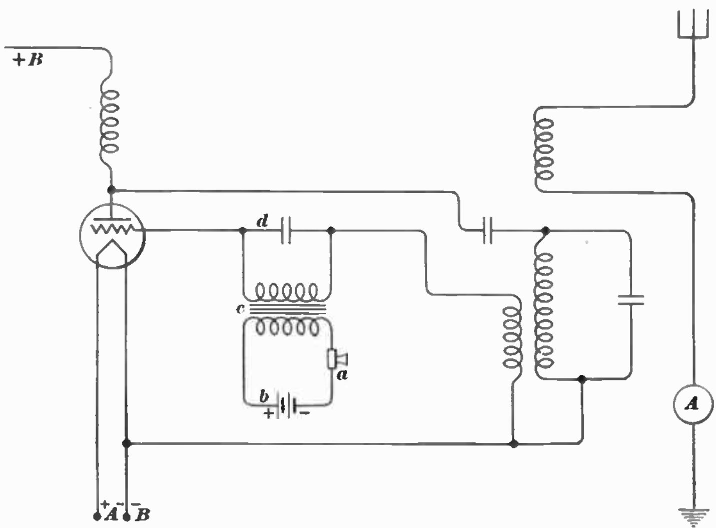


FIG. 16

This result is not entirely obtained with this system of modulation owing to the following facts: The relation between the grid biasing voltage and the antenna current is not linear (and it should be for good modulation); that is, a certain percentage variation in grid biasing voltage does not produce a relative percentage variation in antenna current. In fact, if a circuit condition has been obtained at which point the oscillations are stable, the antenna current is only slightly affected throughout a relatively wide range of variation in the grid biasing voltage. Therefore, these conditions are not favorable for good modulation and by good modulation is meant the faithful reproduction of speech vibrations in the varying of the amplitude of the output radio-frequency current. By very careful adjustment, however, fairly satisfactory operation is possible.

26. Variation of Plate Supply.—The third method of modulation, which depends on the variation of the plate supply to the oscillator tube, is far more efficient than either of the other two methods. By variation in plate supply is meant the variation of the plate voltage, the plate current, or the plate power. This method excels the resistance method because there is no waste in the oscillatory power as there is in the variation of resistance, which might logically be called the *absorption method*. It excels the second method because the relation between plate supply and antenna current is fairly linear over a wide range. In this method a voice voltage (one that varies in accordance with the frequency and amplitude of the sound waves due to speech which actuate the microphone diaphragm) is superposed on the direct-current voltage in the plate circuit of the oscillator tube, thus causing the plate current, and subsequently the plate power, to vary at speech frequencies. A complete variation from zero current to double the normal current of the oscillator tube entails an amount approximately equal to that supplied to the oscillator during normal operation. By normal operation is meant the functioning of the oscillator tube as a generator of radio-frequency currents with a constant plate supply, hence with no superposed variations due to speech. Thus, the modulating device must be capable of supplying this power to the oscillator tube or of controlling its supply from the plate source. The microphone, because of its low current-carrying capacity rating (100 milliamperes), is incapable of controlling the plate supply to the oscillator tube directly, but must effect its control indirectly; and it does this through the medium of an auxiliary tube called the modulator tube.

27. The practical application of the plate modulation system, which is called the Heising method of modulation after Mr. A. R. Heising of the Western Electric Company,

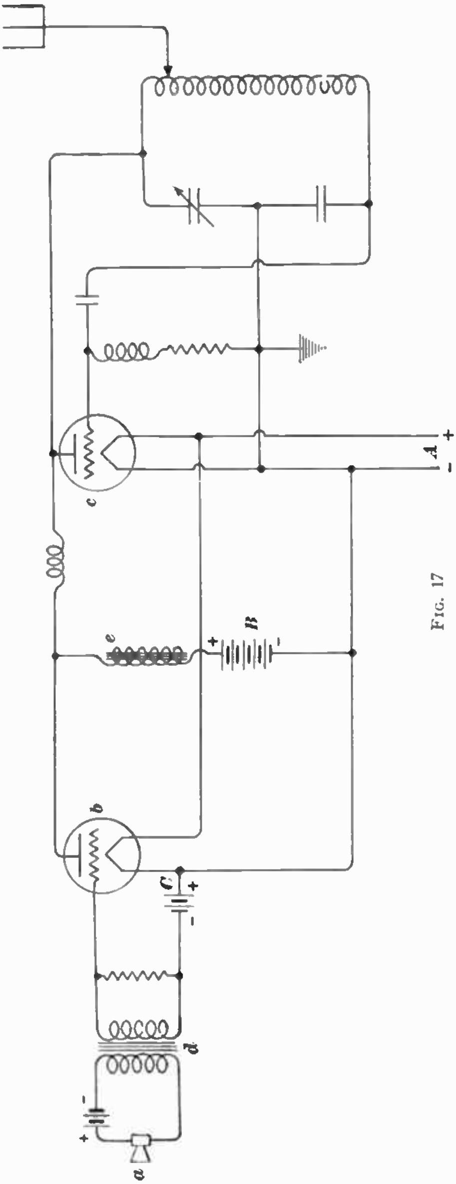


Fig. 17

is shown in Fig. 17. The oscillatory circuit shown here is of the Colpitts type. When the microphone *a* is idle, there is a constant plate supply, both to the modulator tube *b* and the oscillator tube *c*. It follows, then, that the radio-frequency currents in the antenna circuit are of constant amplitude (C. W.) and the output is unmodulated. When the microphone is spoken into, its diaphragm follows the speech-frequency variations and subsequently its resistance varies accordingly. Thus, the direct current in the microphone circuit goes through similar variations and there is a pulsating direct current in this circuit. Alternating voltages are set up in the secondary winding of the microphone transformer *d*, owing to the pulsating currents in the primary winding, and are applied to the grid of the modulator tube. This causes the plate current of this tube to vary accordingly. In the common plate supply to the modulator and oscillator tubes *b* and *c* there is an iron-core choke coil *e* of very high inductance. It is the inherent property of an inductance to oppose any change in the current passing through it, therefore the choke coil in the plate circuit tends to keep the value of the current passing through it constant.

If at any instant the grid of the modulator tube *b* goes positive, the plate current of this tube increases, and since the choke coil *e* tends to keep the total current to both tubes constant, the modulator tube *b* draws current away from the oscillator tube *c* and the current to the oscillator tube decreases. Conversely, when the modulator grid goes negative, the modulator plate current decreases and the oscillator plate current increases because the total supply of current to both tubes is maintained constant by the choke coil. Thus, the average plate current to the oscillator tube is varied at an audio-frequency rate, or speech-frequency, and the amplitude of the radio-frequency antenna current is correspondingly varied.

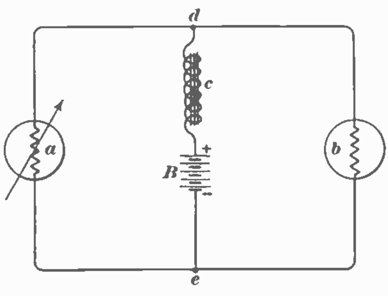


Fig. 18

28. With the aid of Fig. 18 this action can be made clearer. Here the modulator plate-filament circuit has been represented as a variable resistance *a* because its average grid voltage varies at a speech-frequency rate. The oscillator tube plate-filament circuit has been represented as a constant resistance *b*, since its average grid voltage remains constant. The plate source is shown at *B* and the iron-core choke coil at *c*.

Let is be assumed that a 1,000-cycle tuning fork is set vibrating in front of the microphone. The modulator grid voltage and, consequently, plate current, will go through similar variations of the same frequency as the tuning fork. This will make the plate circuit of the modulator tube function as a variable resistance connected across the plate supply. If it is assumed that the modulator plate current changes from zero to twice its normal value and by normal value is meant the value of the plate current passing when the microphone is idle, then it follows that the oscillator plate current must increase and decrease about its normal value to the same extent, since the choke coil functions to maintain the total plate current approximately constant.

If the value of the oscillator plate current is varied at the rate of 1,000 cycles per second, the amplitude of the radio-frequency antenna current will be varied at the same rate. Since the resistance of the oscillator plate-filament circuit is considered constant and since the current through this resistance is changing from zero to twice the normal value, the power expended in this resistance must change from zero to four times the normal value, since power is equal to the square of the current times the resistance. The power is also equal to the voltage across the resistance times the current through it, and since the power changes to four times the normal power, the current only changing to twice normal current, it follows that the voltage across the oscillator resistance and hence the voltage across the points *d* and *e* in Fig. 18 must change to twice its normal value.

29. It has been mentioned that the choke coil *c*, Fig. 18, in the plate feed tended to maintain the total plate current approximately constant. If it held the plate current absolutely constant it would be untrue that there was any change in voltage across the points *d* and *e*. However, the inductance of the choke coil is so high, and since the current passing through it is varying at an audio-frequency rate (1,000 cycles per second in this case) only a slight change in the value of the current through the coil would cause a large change in the voltage across it. The following are some actual figures from radio-telephone sets using this type of modulation: Average value of total plate current, .08 ampere; inductance of choke coil *c*, Fig. 18, 2 henrys; plate voltage, 300 volts.

In this case, if there was a maximum variation in the current through the choke coil *c*, of 20 per cent., at a modulating frequency of 1,000, the maximum voltage drop across the coil *c* would be found by the formula

$$\text{maximum drop} = 2\pi f L I$$

in which $\pi = 3.1416$;
f = frequency, in cycles;
L = inductance;
I = change in current.

Substituting the values, $2 \times 3.1416 \times 1{,}000 \times 2 \times \left(\frac{20}{100} \times .08\right)$ $= 200$ volts.

Thus, the voltage across the points *d* and *e* would vary from $300 - 200 = 100$, to $300 + 200 = 500$. Hence it can be said that the oscillator plate voltage and, therefore, the amplitude of the antenna current varies in accordance with the microphone-diaphragm displacement due to the sounds impinged on it.

RADIO TELEPHONE INSTALLATIONS

2-KILOWAT COMMERCIAL SET

POWER CIRCUITS

30. The fundamentals of the radio-telephone transmitter having been discussed, it will be of advantage to consider a standard 2-kilowatt installation in detail. The schematic diagram of the set is shown in Fig. 19. The source of power is derived from the motor-generator set shown in the figure. The $6\frac{1}{4}$-horsepower driving motor is located in the center of the unit and may require either alternating- or direct-current supply, according to local conditions where the set is to be installed. If the supply is direct current, 115 volts is required. If alternating current is available, a repulsion induction motor is supplied that will run on either 110 or 220 volts, 50- or 60-cycle, single-phase supply.

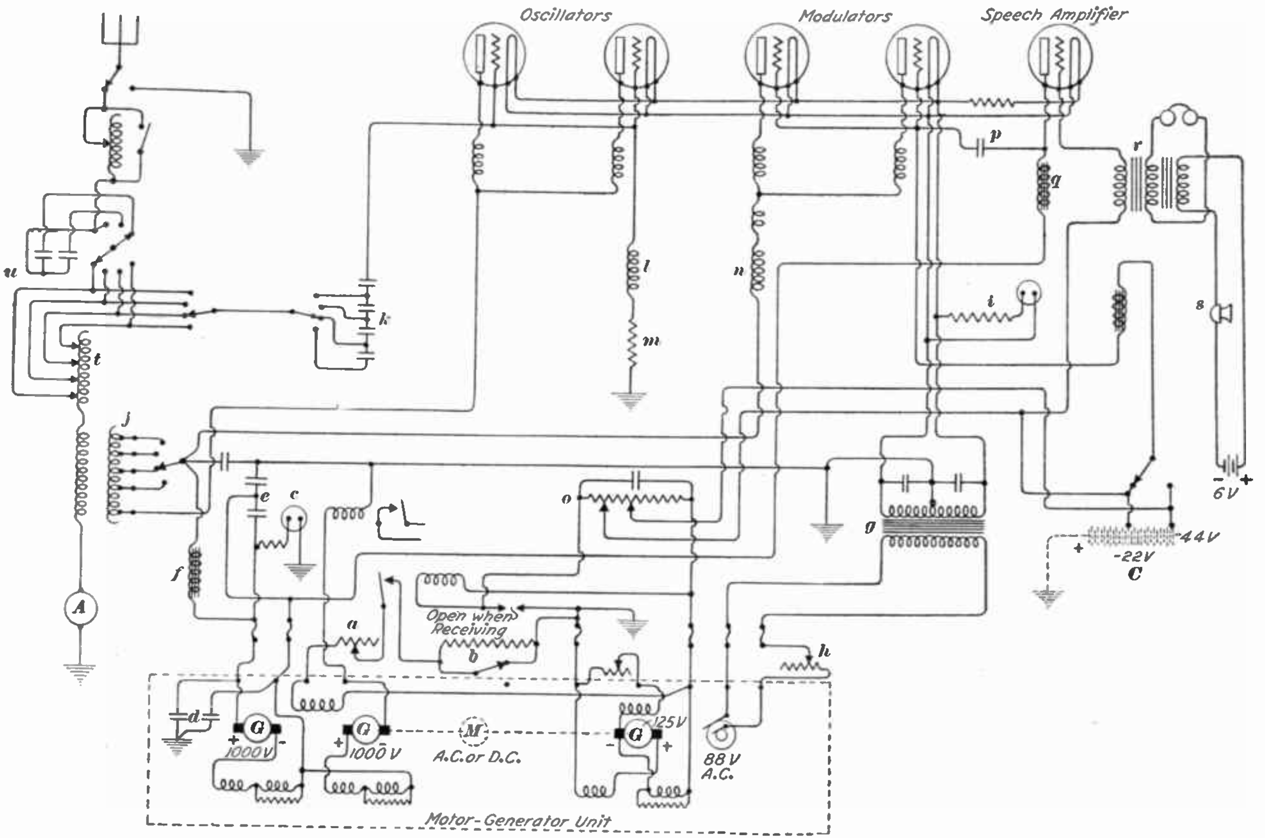

Oscillators
Modulators
Speech Amplifier
Open when Receiving
1000 V
1000 V
A.C. or D.C.
125 V
88 V A.C.
6 V
-44 V
-22 V
C
Motor-Generator Unit

FIG. 19

The plate-voltage generator will supply 1 ampere at 2,000 volts and has a mid-tap for the 1,000-volt supply. This is a flat-compounded machine and is excited from the double-current generator located at the right of the motor. The plate voltage is controlled by means of the plate rheostat *a* in series with the main field of the high-voltage generator, which is energized by the 125-volt direct-current supply from the double-current generator. The power control resistance *b* is also in series with this circuit. This resistance is short-circuited when the power switch on the front of the transmitter panel is set at high power. When this switch is set at low power, the short-circuit is removed and the resistance is in series with the field and field rheostat, thus lowering the plate voltage. The plate voltage is read by the voltmeter *c*, which is connected between the 2,000-volt lead and the ground. There are two protective condensers *d* in series across the high-voltage leads, the mid-point of these condensers being connected to the ground. These are to safeguard against high-voltage surges. The filter condensers *e*, between the plate supply leads and the ground are to smooth out the generator ripple.

31. The double-current generator, Fig. 19, will deliver 4 amperes direct current at 125 volts and 10 amperes alternating current at 88 volts. This is a flat-compounded type of machine and is self-excited. The motor is directly connected to the two generators. The 2,000-volt plate supply is connected to the two 250-watt oscillator tubes and the two 250-watt modulator tubes through the common iron-core choke coil *f*. This reactance *f* is necessary for the application of the Heising system of modulation. The 50-watt speech-amplifier tube receives its plate voltage from the 1,000-volt tap on the plate-supply generator. The 125-volt direct current from the double-current generator is not only used for energizing the field of the plate-supply generator, but it also supplies the negative bias for the grids of the speech-amplifier and modulator tubes.

The 88-volt alternating current is applied to a step-down transformer *g*, the secondary of which is connected to the filaments of the tubes. The filaments of the tubes are all in parallel and the voltage applied to them is controlled by means of the filament rheostat *h* on the primary side of the filament transformer. This rheostat is usually located at the operator's desk and it is possible for him to adjust the filament voltage and check it by the filament voltmeter *i*, which is connected in on the secondary side of the filament transformer. This voltmeter *i* is located on the operator's desk. To heat the filaments of the 250-watt tubes, 11 volts is required, but only 10 volts is required for the 50-watt speech-amplifier tube, therefore a fixed resistance is mounted in series with the filament leads to this tube, of such a value that, with 11 volts at the terminals of the 250-watt tubes, there will be 10 volts at the terminals of the 50-watt tube.

Two by-pass condensers are connected in series across the secondary of the filament transformer and their mid-point is grounded. These condensers form a low-resistance path for the radio-frequency current in this part of the circuit and make it unnecessary for the radio-frequency currents to pass through the high reactance of the secondary winding of the filament transformer in order to get the ground, as would be the case if these by-pass condensers were not in the circuit.

OSCILLATING CIRCUIT

32. The type of oscillatory circuit used is the tickler-coil circuit with inductive plate coupling, the fundamentals of which have been previously discussed. The oscillator plates, Fig. 19, are connected to the positive high voltage through the plate coupling coil *j* and the iron-core reactance *f*. The grid excitation of the oscillator tubes is supplied by means of the capacity coupling to the antenna circuit through the grid coupling condensers *k*. The grid-leak circuit is composed of the grid-leak choke coil *l* and the grid-leak resistance *m*. The choke coil isolates the radio-frequency current from this part of the circuit to reduce losses; and the resistance, together with the direct current passing through it, determines the amount of negative bias on the oscillator grids.

When the filament switch is closed and the filaments are heated to their normal degree, the application of the plate voltage causes an instantaneous surge in the plate circuit, with the result that the antenna is forced into feeble oscillations, the frequency of which depends on the constants of the antenna circuit. The grid circuit owing to its capacitive coupling to the antenna circuit, withdraws some of this oscillating energy with the result that a radio-frequency potential is applied between the grid and the filament. This produces a corresponding change in the plate circuit, which, if the circuits are properly arranged, adds to the effect of the original surge. This cycle of operations is then repeated with the antenna current continually increased until limited by the antenna and tube characteristics.

MODULATOR CIRCUIT

33. The Heising system of modulation is used in the 2-kilowatt set and modulation is accomplished by means of the two 250-watt modulator tubes, Fig. 19, and their associated circuits. In addition to the two modulator tubes there is used a third tube, which functions as a speech amplifier. The plates of the two modulator tubes are connected to the positive high-voltage terminal through the modulator radio-frequency choke *n* and the iron-core reactance *f*. The filaments of the modulator and oscillator tubes being in parallel, the plate circuit is completed through the space between the plate and filament within the tubes and thence to the negative side of the high-voltage generator. The grids of the modulator tubes are connected through a biasing resistance *o* to the negative lead of the 125-volt generator and to the ground, and are also connected to the plate circuit of the speech-amplifier tube through a condenser *p*. The plate of the speech-amplifier tube is connected to the high-voltage source through an iron-core reactor *q*. The grid of the speech-amplifier tube is connected through the secondary of the microphone transformer *r* and the biasing resistance *o* to the negative side of the 125-volt generator and to the ground. The mid-point of the secondary of the filament transformer *g* is also grounded. The primary circuit of the transformer *r* fundamentally consists of a microphone *s* in series with a 6-volt battery and the primary winding of the microphone transformer.

34. The action that takes place in the transmitter set shown in Fig. 19 is as follows: Let it be assumed that current through the primary winding of the microphone transformer is varied at speech frequency owing to the operator's talking into the microphone; then the secondary of the microphone transformer, being connected between the grid and the grounded filament of the speech-amplifier tube, impresses on this grid an alternating potential, the variations of which are in accordance with the sound wave spoken into the microphone. This variation of the speech-amplifier grid potential results in a similar variation in the plate circuit. In other words, the output of the microphone is amplified to an extent determined by the circuit and tube characteristics of the speech-amplifier tube. These amplified variations are in turn impressed on the modulator grid by means of the capacity coupling through condenser *p*. The variation of the modulator-grid potential produces a corresponding change in the plate current and tube impedance. These variations in the modulator plate circuit result in a corresponding increase or decrease of power available for the plate circuit of the oscillator tube because there is practically a constant current supply for both the plate circuit of the oscillator and modulator tubes, which in turn is due to the iron-core reactor *f* in the positive side of the plate generator. Thus, if there is a constant supply of plate current for the combined oscillator and modulator tubes and the supply to the modulator tubes is decreased by negative grids, then the supply to the oscillator tubes must be increased, and vice versa. Thus the radio-frequency output of the set is modulated.

It may be well to note here that the transmitter is supplied with a resistance *o* connected across the 125-volt direct-current supply from the double-current generator. This resistance is shunted with a smoothing condenser so that the generator ripple will not be applied to the grids. By means of suitable taps taken from this resistance, the correct biasing voltage is maintained on the speech-amplifier and modulator grids. If for any reason the commutation of the 125-volt generator should become poor and cause interference, *C* batteries may be used for grid biasing, connected in the circuit as shown by the dotted lines. If this is done, the grid-biasing resistance *o* should be removed from the circuit. The speech-amplifier grid is maintained at the same negative potential, both when the power switch is set for high power and when it is set for low power, but the negative bias on the modulator tubes is doubled automatically when the power switch is thrown from low power to high power.

35. In the actual transmitter there is a wave-change switch located at the top center of the middle panel; it is designed for four positions, thus making it possible to shift with one operation to any one of the four wave-lengths to which the transmitter is tuned. It is a gang switch including four banks that control taps on the following circuits and equipment: plate coupling coil *j*, Fig. 19, grid coupling condenser *k*, loading inductance *t*, and series condenser *u*.

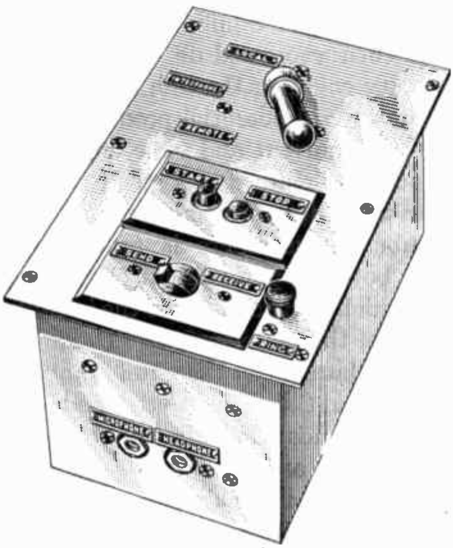


Fig. 20

CONTROL UNIT

36. The control unit situated on the operator's desk is shown in Fig. 20. When the START button is pressed, the automatic starter for the motor of the motor-generator set, functions, and the motor is brought up to full speed automatically. Then the SEND-RECEIVE button is pressed to the SEND position, thus applying plate and filament voltage to the tubes. The filament voltage is adjusted to 11 volts by means of the filament rheostat and the plate voltage to 2,000 volts, by means of the plate rheostat. The transmitter is now ready for operation, and if the operator plugs his microphone in the MICROPHONE jack in the control unit, with the signal switch on the LOCAL position, he can modulate the set by talking into the microphone. If there is another microphone located at a distance from the transmitter, the local operator presses the RING button, which rings a bell at the distant position and with the signal switch on INTERPHONE the local operator can converse with the distant operator without modulating the set. Then, if the remote-control operator is ready, the local operator sets the signal switch at the REMOTE position and the remote-control operator can modulate the set. When the conversation has been completed and it is desired to shut down the set, the SEND-RECEIVE switch is pressed to the RECEIVE position and the STOP button is pressed, thus opening the circuit to the motor, and the motor-generator set comes to a stop. This type of transmitter set has been installed in many ship and shore stations.

SIMULTANEOUS TRANSMISSION AND RECEPTION

TRANSMITTER AND RECEIVER FAR APART

37. The radio-telephone transmitter has been considered by itself; now the circuit arrangement and apparatus necessary to carry on simultaneous transmission and reception will be discussed. By simultaneous transmission and reception is meant the equivalent of talking over the wire telephone where it is possible to talk and listen at the same time, except, of course, that in radio transmission of this type, the air takes the place of the wires between stations. This method of operation is sometimes referred to as duplex radio communication. In Fig. 21 is shown the ideal arrangement for duplex communication. The transmitting and receiving sets *T* and *R* at station *A* are located 5 miles apart, with all the controls installed in the receiving station. The microphone and transmitter controls are wired over to the receiving station, so that it is possible to start the transmitter and control or modulate its output from the receiving station. The assumption, here, is that the transmitter *T* at station *A* is tuned to 400 meters and the receiver *R* to 350 meters. The receiver must be of a selective type, either a superheterodyne or a tuned radio-frequency receiver. Station *B* is 100 miles from station *A* and the transmitter *T* and the receiver *R* here, also, are located 5 miles apart. At this point, however, the transmitter *T* is tuned to 350 meters and

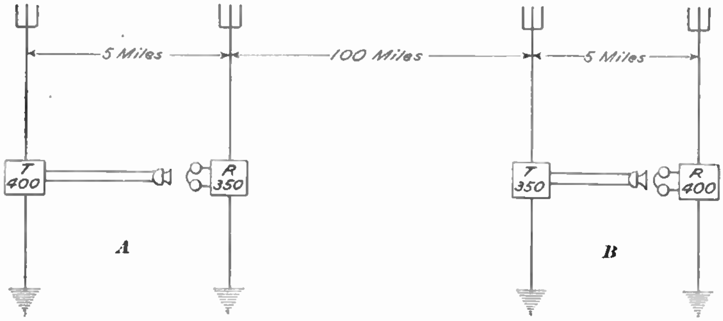


FIG. 21

the receiver *R* to 400 meters. When the operator at station *A* talks into the microphone, a 400-meter voice-modulated wave is radiated from his transmitting antenna. His receiver being tuned to 350 meters does not pick up the 400-meter wave but the operator at station *B* who has tuned his receiver to this wave-length hears the voice from the distant station and answers, speaking into the microphone at station *B*. Thus, a voice-modulated wave is radiated from the transmitting antenna at station *B*, but in this case the wave-length of the radiated energy is 350 meters, so it does not interefere with the local receiver, which is set at 400 meters, but is heard by the operator at station *A*, who has his receiver tuned to this wave-length. Thus, the two operators can talk back and forth just the same as though they were talking over the land line telephone.

TRANSMITTER AND RECEIVER NEAR EACH OTHER

38. Use of Loop Antenna.—It may not be feasible to locate the transmitter and the receiver 5 miles apart at one of these stations, hence they may be located only a mile apart. It would then probably be sufficient to use a loop for reception instead of the overhead antenna to eliminate the interference from the transmitter. In this case it would not be necessary to use any interference-elimination circuits in conjunction with the loop, provided, of course, a selective type of receiver is used.

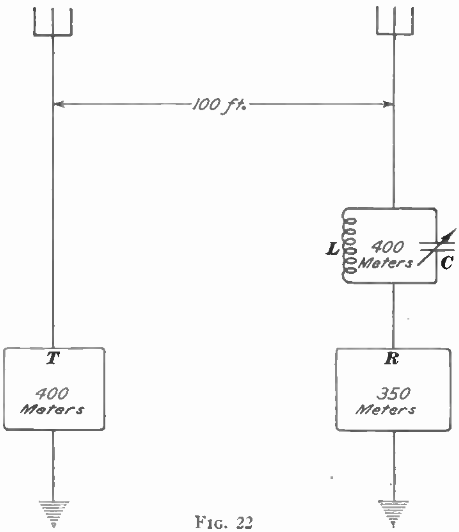


Fig. 22

39. Series Anti-resonant Circuit. The foregoing requirements cannot always be fulfilled. On land it is usually practical and possible to locate the transmitter and the receiver a few miles apart but on a ship at sea, for instance, this would be impossible. Therefore, if duplex communication is to be carried on from ship to shore it will be necessary, on ship-board, to use some method of eliminating the interference from the local transmitter. It is best to have the transmitting and receiving antennas as far apart and as loosely coupled as possible. When the transmitting antenna is radiating energy, a considerable amount is picked up by the receiving antenna owing to the proximity of the two antennas, and even when the receiver is detuned 50 meters from the transmitter wave-length a large amount of interference is experienced because of the strong voltage induced in the receiving antenna.

One way of eliminating this local interference so that duplex work is possible is shown by the schematic diagram in Fig. 22. Here the transmitting and receiving antennas are only 100 feet apart and the interference is eliminated by means of the antiresonant circuit in series with the antenna lead to the receiver. This circuit is also composed of an infinite impedance circuit. The inductance *L* and the capacity *C* are so chosen that they tune to 400 meters, the wave-length of the transmitter. It is the property of an inductance and capacity in parallel, when connected in series in a given circuit, to offer extremely high impedance to the passage of any current of the frequency to which the parallel circuit is tuned. This circuit in this case is tuned to 400 meters and the impedance curve is shown in Fig. 23. It can be seen from this figure that the impedance is very high for the wave-length to which the local transmitter is tuned, but is very low for the wave-length of the distant transmitter.

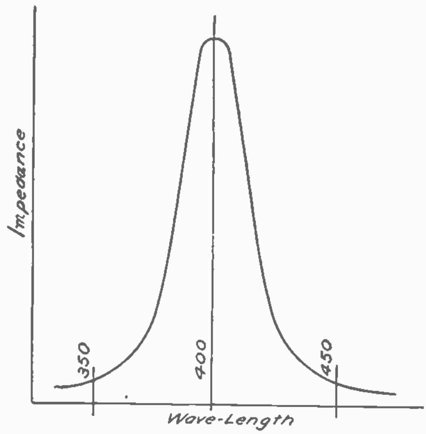


Fig. 23

Thus, the weak signals from the distant transmitter would come through with very little impedance in their path and the answer could be sent back from the local transmitter without interfering with reception.

40. Series Resonant Circuit.—Another circuit to eliminate local interference in an installation of the type just considered is shown in Fig. 24. The inductance and capacity may have the same values as were used in the previous case, but instead of being connected in parallel and then in series with the antenna circuit, they are connected in series and the combination is in parallel with the antenna circuit. They function just the opposite in this case because when an inductance and a capacity are connected in series and the combination is connected in parallel with a given circuit, they offer a very low impedance to the passage of any current of the frequency to which they are tuned; hence, they tend to shunt the given circuit. This is called a *series resonant circuit*, or a *zero impedance circuit*. In this case it is tuned to 400 meters, and the receiving circuit is tuned to 350 meters.

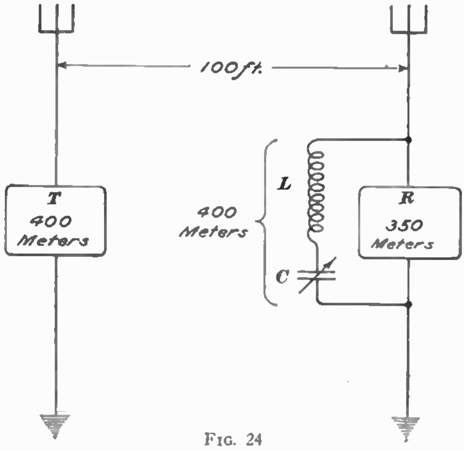


FIG. 24

41. The zero impedance circuit *L C*, Fig. 24, will practically short-circuit all the 400-meter energy picked up by the receiving antenna to the ground, but on the other hand will offer a very high impedance to the current at the 350-meter wave-length. Then the weak 350-meter energy from the distant station will follow the path of least resistance and will pass through the primary coil of the receiver rather than through the 400-meter zero-impedance circuit *L C* that offers considerable impedance to the 350-meter wave.

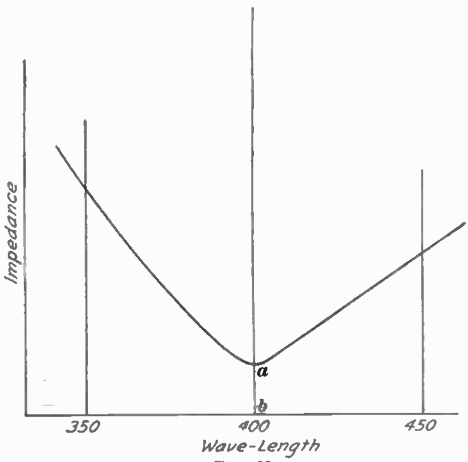


FIG. 25

The impedance curve for the zero-impedance circuit of Fig. 24 is shown in Fig. 25. The lowest value is reached at the 400-meter point *a*. Here the inductive reactance and the capacity reactance balance out, and the amount of impedance *a b* is due to the ohmic resistance of the circuit. It can also be seen that at 350 meters the impedance of the circuit is very high.

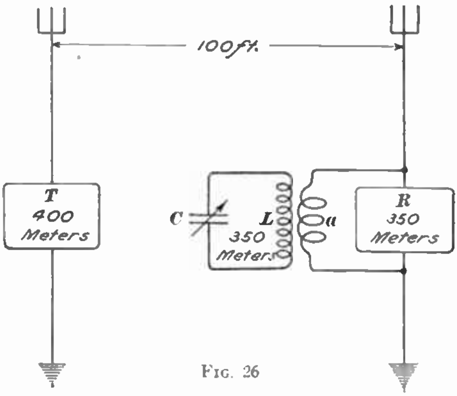


FIG. 26

42. Coupled Resonant Circuit.—Another type of circuit that can be used in duplex communication under the conditions cited in the previous case is shown in Fig. 26. Here, two or three turns *a* of heavy wire are shunted across the antenna and the ground binding posts of the receiving set and this coil is closely coupled to the tuned circuit *L C*. The few turns composing the coil *a* should be wound directly over the coil *L*. The parallel circuit is so closely coupled to the coil that is shunted across the input to the receiver that if it is tuned to 350 meters it produces the effect of an infinitely high impedance to the passage of all current of that frequency, through the coil *a*. The impedance of coil *a* would be as shown in Fig. 27.

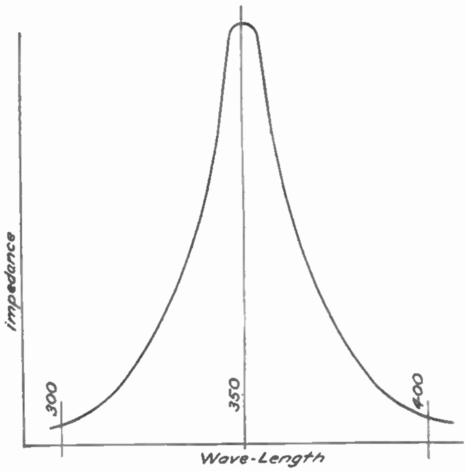


FIG. 27

It would have a very high impedance at 350 meters but would have practically nothing but its own ohmic resistance at all other wave-lengths. Thus, energy picked up by the receiving antenna from the local transmitter would be short-circuited to the ground, and the 350-meter energy from the distant station would follow the path of least resistance and pass through the primary coil of the receiver. Any wave-length in the immediate vicinity of 350 meters would be received efficiently, but all others would be short-circuited to the ground. It is important to note here that while the preceding two types of trap circuits eliminated one prticular frequency and accepted all others, this last type *accepts* one particular frequency and *eliminates* all others.

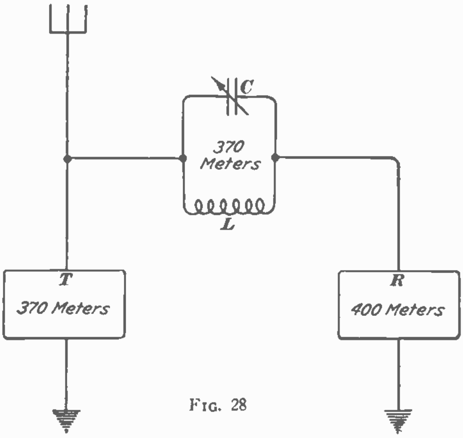


Fig. 28

43. Duplex Arrangement on Board Ship.—In the case of the installation aboard a ship for duplex communication, it might be desirable to use the same antenna for transmitting and receiving. This would mean that it would be necessary for the receiver to detect the weak signals picked up from the distant transmitter and amplify them and produce good quality and volume, free from interference, while there are, for example, 15 amperes of modulated radio-frequency current passing in that same antenna. These conditions, of course, make the feat of duplex communication much more difficult, but it can be done efficiently and practically. The circuit arrangement is shown in Fig. 28. The receiver used in this case is of the superheterodyne type. The transmitter is tuned to 370 meters, for example, and the receiver is tuned to receive 400-meter signals from the distant station. The trap circuit used here is of the antiresonant type and because it is tuned to the same wave-length as the transmitter, it offers a very high impedance to the passage of any current of that frequency. However, since there is so much energy in the antenna circuit of that frequency, a little is bound to get through to the primary circuit of the superheterodyne receiver. This energy is used instead of using a separate oscillator to beat with the incoming signal in the receiver circuit. No local oscillator is necessary in a superheterodyne receiver to be used under these conditions.

44. The frequency of the local transmitter is $300{,}000{,}000 \div 370 = 811{,}000$ cycles. The frequency of the distant transmitter is $300{,}000{,}000 \div 400 = 750{,}000$ cycles. The beat frequency is $811{,}000 - 750{,}000 = 61{,}000$ cycles. The wave-length of the beat note is $300{,}000{,}000 \div 61{,}000 = 4{,}900$ meters. The preceding is calculated in round figures and is not carried out to the last decimal place. Thus, the distant 750,000-cycle signals beat with the 811,000 cycles, which is the frequency of the local transmitter, and form a 61,000-cycle beat note. In terms of wave-length it can be said that the distant 400-meter signal has been changed into a 4,900-meter signal at the receiving station. This 4,900-meter beat note is detected by the high-frequency detector in the receiver and is amplified by the intermediate-frequency amplifier. The audio-frequency envelope over the 4,900-meter beat note is detected by the low-frequency detector and is amplified in the audio-frequency amplifier circuit. This system has been tried out and proved satisfactory.

BROADCASTING TRANSMITTERS

COMMERCIAL AND BROADCASTING TRANSMITTERS

45. There is a marked difference between the commercial type of radio-telephone transmitter previously described and the type of transmitter used for broadcasting. The limits for both the mechanical and electrical designs of the former are definitely fixed by economic and operating conditions. On the other hand, the economics of the broadcasting station are indefinite and the method of operation is determined by factors far removed from those governing commercial traffic.

The commercial radio-telephone transmitter is designed in such a manner that it can be used for either telegraph or telephone communication. On the commercial type of transmitter it is possible, by means of a wave-change switch, to change to any one of half a dozen wave-lengths to which the set is tuned and by means of a separate gang switch to select any one of the following methods of transmission: continuous-wave telegraphy (C.W.), interrupted continuous-wave telegraphy (I.C.W.), and telephone. The broadcasting transmitter, however, is limited to one particular wave-length. The oscillatory circuits are tuned to that one wave-length and all the associated apparatus is adjusted for maximum efficiency at that particular wave-length In general, the commercial transmitter is required to transmit only the band of frequencies necessary to handle commercial telephony, whereas the broadcast transmitter must be capable of transmitting frequencies from the deepest tone of the organ or orchestral instruments to the highest note of the piccolo or flute.

46. The broadcast transmitter has been subjected to numerous refinements that, owing to both economic and operating conditions, could not be incorporated in the commercial type of transmitter. All apparatus in a broadcasting station is in duplicate to insure continuity of service. The general requirements of the broadcasting station are as follows:

The station must be ready to operate at all times so that the director may at any time handle a special program; continuity of service is absolutely necessary—the equipment must be so designed and operated that there will be no interruptions during the program; the quality must be of the highest order; the transmitter frequency must remain constant under all operating conditions.

LAYOUT OF STATION

47. Power Plant.—In Fig. 29 is shown the plan view of the layout for a modern broadcasting station. In this case the power house is situated 1,000 feet from the studio, but this is not a necessity, and in many instances the power house is located adjacent to the control room.

The power plant contains all equipment necessary for the generation, modulation, and radiation of radio-frequency power. This apparatus is located in what is called the power house, and consists of the following equipment supplied in duplicate to insure continuity of service: Kenotron rectifier unit to supply high-voltage direct current; radio-frequency generator utilizing high-power vacuum tubes as oscillators; modulator unit, utilizing high-power vacuum tubes as modulators.

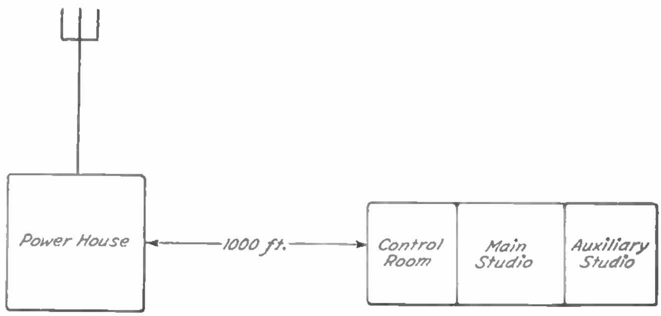


Fig. 29

48. Control Room and Studio.—The control room, Fig. 29, contains all amplifying and switching equipment. The main studio consists of the usual room prepared and furnished especially for broadcasting service. The walls and ceiling are covered with draperies to prevent the reflection of the sound waves. All microphone and control circuits are carried in lead-covered cables laid behind the wall draperies. Connection boxes are usually located along the base board near the floor for the microphone outlets. The auxiliary studio is similar to the main studio but is generally much smaller, and is used principally for readings and lectures.

DISTRIBUTION OF MICROPHONES

49. Pick-Up Devices.—Several types of microphones, or pick-ups, are used in broadcasting stations. The ordinary carbon-granule transmitter is the one that is most frequently used. Other types such as the magnetic, condenser, etc. may be found at the various broadcasting stations. The magnetic transmitter is similar to the magnetic amplifier used in large commercial telegraph stations. In this connection a microphone takes the place of the telegraph key. The condenser transmitter, as the name implies utilizes the condenser principle for its operation. One of the plates of such a condenser is made rigid, the other movable. Sound waves striking the movable plate cause it to vibrate, thereby varying the capacity of the condenser so formed. The external appearance of the microphone that is frequently used in broadcasting stations is shown in Fig. 30.

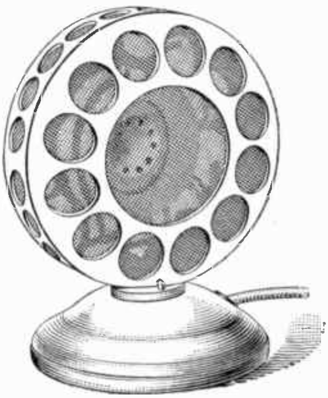


Fig. 30

50. Importance of Proper Placing of Microphone.—The pick-up device, or microphone, is one of the most important units associated with a broadcasting station, since it is depended on to transform faithfully the sound vibrations imposed on it, into electrical oscillations that can be handled efficiently by the rest of the apparatus. In the studio, a separate microphone is sometimes used for a particular instrument, such as a piano, and the soloist usually has an individual microphone. A great portion of the success of any broadcasting station depends on the operation of the studio. The proper placing of the artists and the relation of the various instruments of the orchestra, band or chorus, affects the transmission very materially.

The problem of broadcasting from churches and other places outside of the regular studio has received considerable attention. A typical arrangement of the microphones necessary to broadcast a church service is shown in Fig. 31. Eight microphones are used in this case besides the operator's microphone, which is marked *0* in Fig. 31. By means of a control unit at the operator's position, any combination of microphones may be switched into service. Fig. 32 is a schematic diagram showing the operator's control position with the nine incoming microphone circuits and the two outgoing circuits to the control room at the studio. The second circuit to the control room is available for use in case the first circuit becomes noisy or otherwise inoperative.

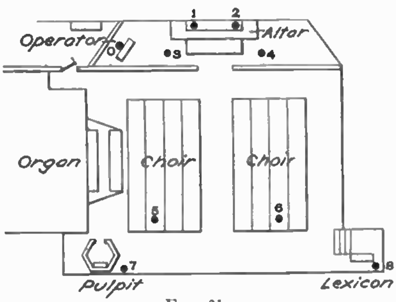


FIG. 31

SPEECH AMPLIFIER

51. Kinds of Speech Amplifiers.—In the commercial type of radio-telephone transmitter previously described a 50-watt tube was used as a speech amplifier. In the modern type of broadcasting transmitter the speech that actuates the microphone diaphragm passes through an elaborate system of speech amplifiers before it reaches the speech amplifier tube in the transmitter unit, as shown schematically in Fig. 33.

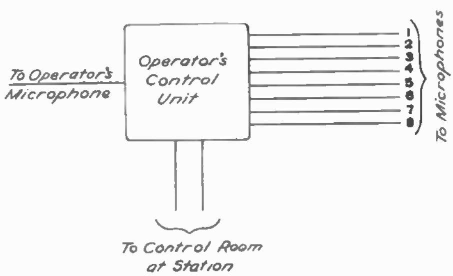


FIG. 32

The microphone circuit *a* is coupled by means of the transformer *b* to the grid circuit of the first amplifier tube *c*. This tube is a small power tube known as the UV-202. The second

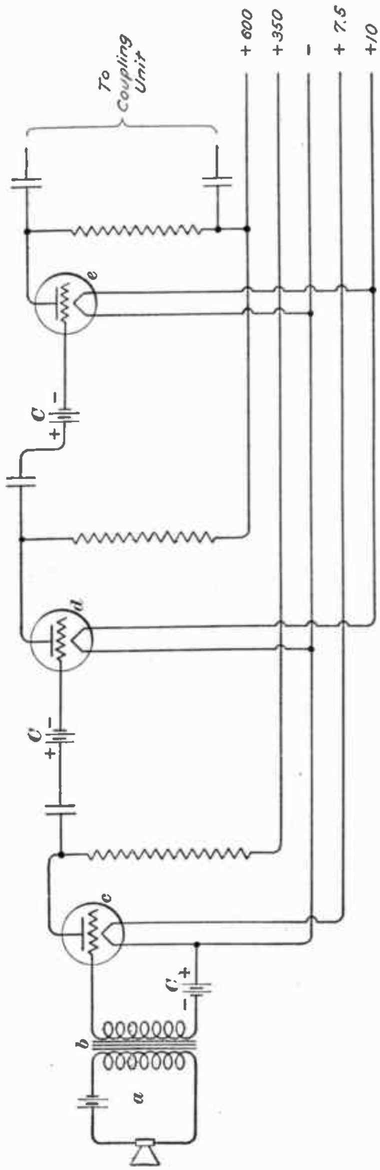


Fig. 33

amplifier tube *d* and the third *e* are coupled together by means of high resistances with blocking condensers in the grid circuits. Tubes *d* and *e* are of the UV-203 type. The output of the tube *e* is connected to a coupling unit that connects the speech amplifier with another amplifier at the power plant.

52. In Fig. 34 is a plan view showing the lay-out of the first-, second-, and third-stage amplifiers with the coupling units and the lines to the power house. In this case, there are ten first-stage amplifiers. Numbers *1* and *2* are for the announcer's microphones in the main and the auxiliary studios. Number *3* is for time signals, numbers *4* and *5* are on church circuits, and numbers *6* to *10*, inclusive, are on concert circuits. Four different types of first-stage amplifiers are provided and are selected according to the pick-up device used. Certain amplifiers are assigned to certain classes

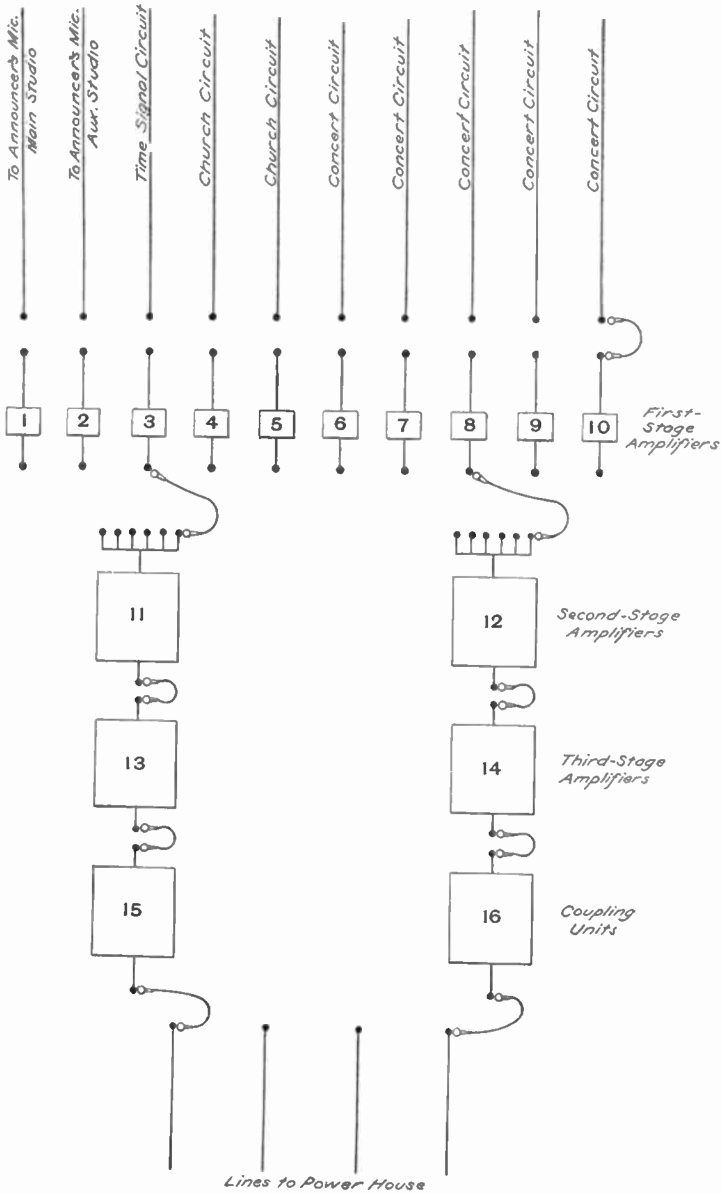

To Announcer's Mic. Main Studio
To Announcer's Mic. Aux. Studio
Time Signal Circuit
Church Circuit
Church Circuit
Concert Circuit
Concert Circuit
Concert Circuit
Concert Circuit
Concert Circuit
1
2
3
4
5
6
7
8
9
10
First-Stage Amplifiers
11
12
Second-Stage Amplifiers
13
14
Third-Stage Amplifiers
15
16
Coupling Units
Lines to Power House

FIG. 34

of service. For example, each studio has its own announcer's amplifier, which may be of the type shown in Fig. 35 or of that in Fig. 36. The former is a first-stage amplifier that is used in conjunction with a single-button type of microphone.

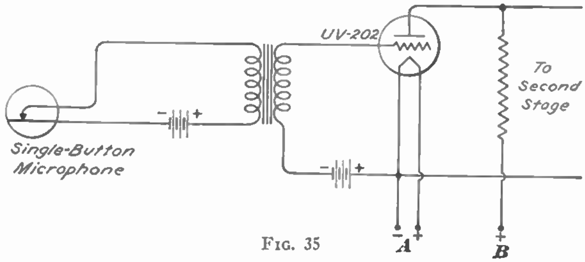


FIG. 35

The latter is the type of circuit used with the double-button type of pick-up device.

53. Certain amplifiers are used for broadcasting from places other than the studio. For example, in Fig. 37 is shown the circuit arrangement where the condenser type of microphone is used. In this case the output of the microphone circuit is

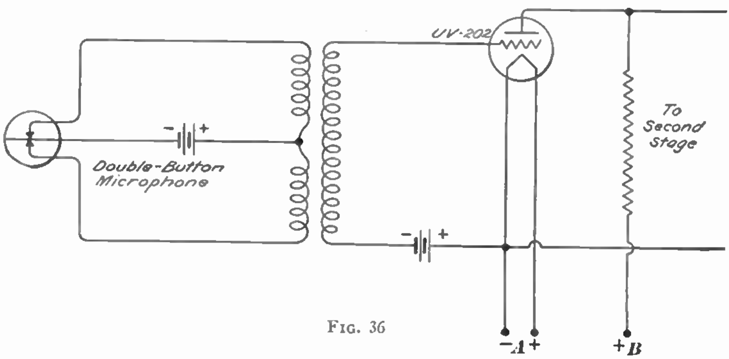


FIG. 36

put through two stages of resistance-coupled amplification before being put on the line to the control room at the studio. After arriving at the studio, this energy passes through another stage of amplification before being passed to the 50-watt second-stage amplifier. It is to be noted that all the stages ahead of the 50-watt tube or second-stage amplifier are referred to as first-stage amplifiers. In other words, they are those stages of amplification using the lowest-capacity tubes.

54. Another type of amplifier that is used a great deal for broadcasting concerts and other similar forms of entertain-

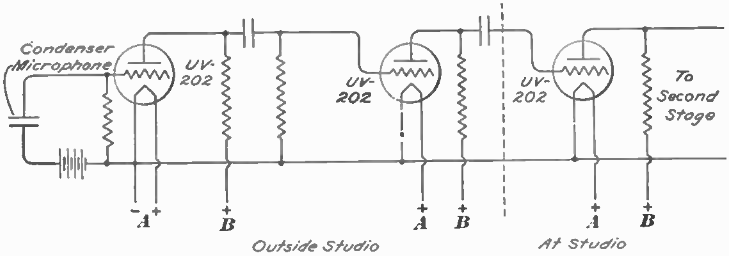


FIG. 37

ments is shown in Fig. 38. The push-pull amplifier shown here is located at the concert hall and the output from this amplifier is put on the line to the studio. At the studio, the incoming energy is amplified by a 5-watt tube and the output of this tube is applied to the grid of the second-stage amplifier tube.

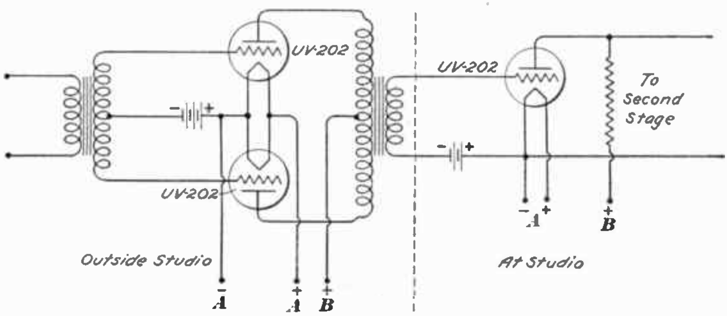


FIG. 38

55. **First-Stage Amplifier.**—Each first-stage amplifier has its own output control, filament control, and listening-in jack. The output circuits of any one of the ten first-stage amplifiers shown in Fig. 34 may be plugged into either one of two second-stage amplifiers. The input circuits of the second-stage units include a number of jacks connected in parallel, thus permit-

ting a number of first-stage amplifiers to be plugged into one second-stage amplifier. For instance, if the first-stage amplifiers, numbers *1*, *3*, and *6* were all plugged into second-stage amplifier number *11* it would be possible for the local-control operator (it is assumed that a concert is coming in on number *6*) to cut out the concert and cut in the announcer's microphone at the studio by the single throw of a switch. The announcer at the studio might then broadcast as follows: "The concert from the Waldorf-Astoria will be interrupted for a few minutes for the retransmission of the Arlington time signals." Then with another throw of the control switch the announcer's microphone at the studio could be cut out and the time signals cut in. At the end of the retransmission of time signals the concert could again be thrown on the air.

56. Second-Stage Amplifier.—The output of the second-stage amplifier may be plugged into either of two third-stage amplifiers. Both the second- and third-stage amplifiers use a 50-watt tube operated at a plate potential of 600 volts. The output of the third-stage amplifier may be plugged into either of two filter units designated as coupling units in Fig. 34. The output of either filter unit can be plugged into any of four lines to the power house where the oscillator and modulator units are located.

ARRANGEMENT OF APPARATUS IN POWER PLANT

57. The layout of the apparatus in the power house is shown in Fig. 39. This constitutes the transmitter, which consists of an oscillator, a modulator, and a speech amplifier unit corresponding to the commercial telephone transmitter described previously. In the commercial transmitter the speech amplifier in the transmitter unit is the first and only stage of amplification; whereas, in this broadcasting layout, the speech-amplifier in the transmitter unit constitutes the fourth stage of amplification. Any of the lines from the control room may be plugged into any one of the four fourth-stage amplifiers. There are two amplifiers for transmitter number *1* and two for transmitter number *2*. One of the two for each transmitter is a push-pull amplifier and the other is a reactance-coupled amplifier. Either may be used, according to operating conditions. In these amplifiers, 250-watt tubes (UV-204) at a plate potential of 2,000 volts are used. The output of the fourth-stage amplifier is plugged into the modulator unit, which

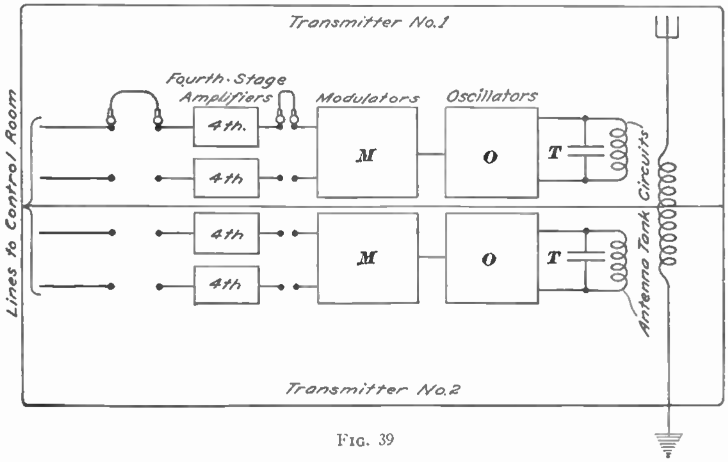


FIG. 39

consists of five 1-kilowatt tubes (UV-206). The oscillator utilizes a tank circuit loosely coupled to the antenna circuit to maintain constant frequency. A *tank circuit* is simply a tuned intermediate circuit, which transfers the power output of the oscillator to the antenna circuit, and the frequency of the radiated energy is determined chiefly by the constants of the tank, or dummy, circuit. The oscillator uses one 5-kilowatt tube (UV-208).

CARRIER-CURRENT TELEPHONY

LOW-FREQUENCY AND HIGH-FREQUENCY TRANSMISSION

58. The proper physical conception of carrier-current transmission and the characteristics that differentiate it from ordinary wire transmission on one hand, and from radio transmission on the other, will first be considered. Ordinary telephone and telegraph circuits make use of electromagnetic waves guided by wires. The wires play so important a part that they may be considered as conveying the electrical energy; but, as a matter of fact, the energy is largely transmitted outside the wires. The energy lost or dissipated in the wire owing to its resistance, however, must not be confused with the energy transmitted in it.

In the carrier system the electromagnetic waves are transmitted in just the same manner as those of the ordinary telephone or telegraph circuit, except that they are of higher frequency. The main difference, then, between carrier and ordinary telephone or telegraph lies primarily in the form given to the electric waves that carry the messages. In the ordinary telephone system a direct current is allowed to pass through a microphone, and the voice frequencies vary the resistance of the transmitter in such a way that the amount of direct current rises and falls in accordance with the voice frequencies. In the ordinary telegraph system a direct current is also used, but this is broken into dots and dashes by the opening and closing of contacts.

59. In the carrier system a very similar process goes on, except that instead of using direct current an alternating current is used, the volume of which is controlled in accordance with the variations of the transmitter. In the ordinary system, then, it may be said that a direct current is modulated. In the carrier system an alternating or high-frequency current is modulated. A high-frequency current on which the signaling variations are thus imposed has come to be regarded as the *carrier* of the signaling variations and hence to be designated as the *carrier current*. Thus, the system has come to be called a *wire carrier system* or more simply a *carrier system*. The use of this principle has resulted in a very important advantage; namely, several messages may be transmitted over one circuit simultaneously. This follows from the fact that carriers of different frequencies may be chosen for the several messages and that the frequencies that result from modulating these different carriers may be put together on a telephone line and at the end the currents of different frequencies may be separated by means of properly designed filters.

COMPARISON OF CARRIER CURRENT WITH RADIO

60. From the foregoing may be seen the difference between carrier and the ordinary telephone and telegraph transmitters. When either of these is compared with radio, there may be found a fundamental difference between guided and unguided transmission. The characteristic feature of radio is, of course, that the waves are unguided. Even when sent with a certain degree of directivity, they spread over a wide area and impinge on all the radio receiving stations in that area. Radio is, then, an unguided broadcasting method of transmission. The guiding of electromagnetic waves should not be confused with the so-called directive, or beam, sending and receiving in radio. By multiple antennas or similar arrangement it is possible to cause radio transmission to be much stronger in a desired direction than in all other directions. This action, however, is carried out only at the place of transmission or reception, whereas the wires of an ordinary carrier circuit guide the waves throughout their complete course from the transmitting end to the receiving end.

CARRIER-CURRENT COMMUNICATION ON TRANSMISSION LINES

61. Commercial Applications of Carrier Currents.—The use of high-frequency currents for telephone and telegraph communication over line wires is of considerable importance to many commercial enterprises. The telephone companies use this system to create additional channels for communication over existing lines. Power companies can establish communication by this means between the stations without constructing extra telephone lines. Transmission similar to radio broadcasting can be arranged; this, of course, is limited to the patrons or subscribers whose premises are connected by wire with the power company. Transportation companies utilizing electric current for the propulsion of rolling stock may use the line carrier system for dispatching purposes, and also to communicate with persons on board the moving vehicle; in both these cases the same wire that carries the power current is used to direct the high-frequency carrier current to its destination. In cases of emergency, for example, when the line wire is broken and ordinary low-frequency communiction cannot be maintained, the carrier system may serve as a temporary remedy for the trouble. Even though there is a break in the wire, the high-frequency carrier current is able to bridge the gap the same as in radio communication.

It should be remembered that the high-frequency carrier system possesses the advantages of both the radio and the line systems. Like the radio telephone it requires no additional circuit, and like the wire telephone it permits of directive transmission.

62. Outline of Carrier-Current System.—A three-station carrier-current system is shown schematically in Fig. 40. The wire *a b* is one of the conductors of a power transmission line. This wire serves as a guide for the high-frequency carrier currents. At each of the stations, *A*, *B*, and *C*, a transmitter *T* and a receiver *R* are provided. A direct connection cannot be made from the sets to the line wire, so coupling wires *c* are provided, one at each station. Each of the coupling wires runs parallel with the line wire a distance of two or three spans, the space between the wires being great enough to prevent them from coming in contact with each other. At each of the stations a switch *d* connects the coupling wire with either the transmitter or the receiver.

Normally all the stations have the coupling-wire switch *d* turned to the receiver contact. In Fig. 40, the apparatus at station *A* is arranged for transmission, and at stations *B* and *C* the receivers *R* are connected to their coupling wires. The operator at station *A* may send his message to either one or

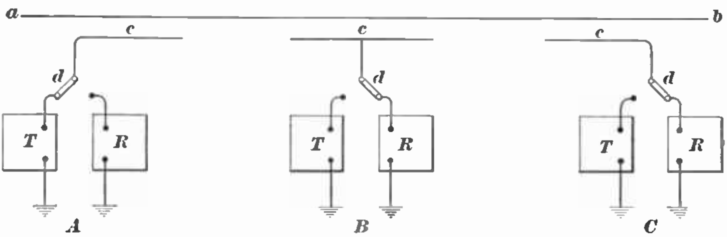


FIG. 40

both of the stations *B* and *C*, and if the operator at either one of the stations wishes to respond he turns his coupling-wire switch to the transmitter contact and uses the transmitter. Since the operator at station *A* turns the switch *d* to the receiver contact immediately after transmitting his message, he will thus receive the desired response from either one of the other stations.

63. High-Frequency Transmitter for Line Use.—The circuits of a 250-watt carrier-current transmitter are shown in Fig. 41. The coupling wire *a* is connected through a fuse *b* and a high-frequency choke coil *c* to the ground. The fuse *b*, the choke coil *c*, and the gap *d* serve as protection for the apparatus in case the coupling wire should come in contact with the high-tension power line.

Four tubes are required for the proper operation of this transmitter. The tube *e* is the oscillator. The oscillations generated by the tube *e* are amplified by the power amplifier tube *f* and transferred to the radiating circuit. The Heising

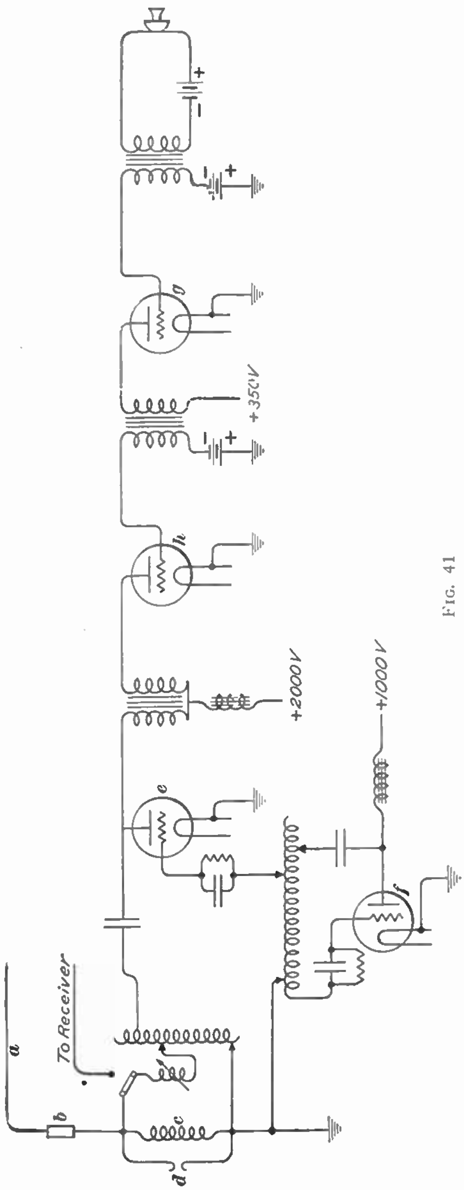


FIG. 41

system of modulation is employed. The voice currents are first amplified by the speech-amplifier tube *g* before they are delivered to the modulator tube *h*. The energy absorbed by the modulator tube *h* modulates the high-frequency oscillations in the amplifier circuit, which, in turn, has a corresponding effect on the transmitted energy. In the actual transmitter, means are provided for signaling the other stations and also for switching easily from a transmitting to a receiving condition.

64. Receiver. The circuits of the receiver used in conjunction with the transmitter of Fig. 41 are shown in Fig. 42. The input circuit of the first radio-frequency amplifier tube *a* consists of a tuned secondary, which is adjusted by means of a variable condenser.

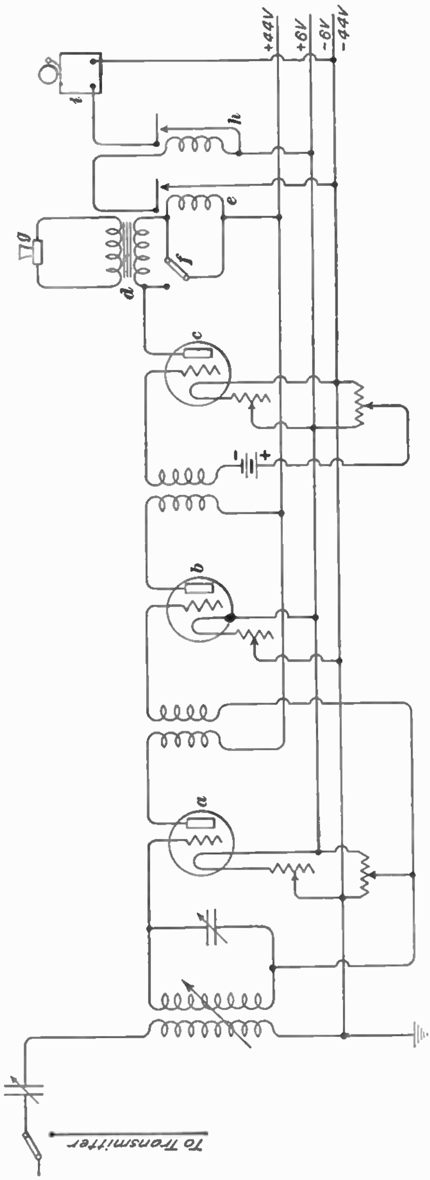


FIG. 42

From the first tube the energy is transferred to a second amplifier tube *b* through a fixed radio-frequency transformer. The detector tube *c* then receives the signal and converts it to an audible frequency.

The plate circuit of the tube *c* includes the primary of the telephone-receiver transformer *d*, and the winding of a sensitive relay *e*, either one of which may be short-circuited by the switch *f*. In the position shown, the switch *f* short-circuits the winding of the relay *e*, and the plate current passes through the primary of the transformer *d*. The receiver when so arranged is said to be in the listening position, for the telephone receiver *g* is active.

When the switch *f* is in contact with the other stop, the transformer *d* is short-circuited, and the relays *e* and *h* are in condition to be energized. When the oscillator at the transmitting station is active, the relay *e* at the receiving station is energized, closing the circuit of relay *h*. The relay *h* in turn closes the circuit through bell *i*, which then rings. A system of code ringing may be arranged to signal any one or more operators on the line. For example, if the operator at station *A*, Fig. 40, desires to call the operator at station *B*, he will ring once. Two short rings would be reserved for the operator at station *C*. The ringing energy is interrupted by interrupting the generation of oscillations in the tube *e*, Fig. 41.

65. A more elaborate scheme of signaling may be employed, especially when there is a large number of stations on the same line. The arrangement may be such that only one station is called at one time, without ringing the bells at the other stations. Both the transmitting and receiving sets must be equipped with special signaling apparatus similar to that used in telephone train dispatching. The transmitting device is an interrupter that breaks up the continuous wave into a series of impulses. The receiving device is a form of selector that closes the bell circuit when the proper number of impulses have been received. Each selector requires a different number of impulses to close the bell circuit.