RADIO THEORY *and* OPERATING

FOR THE RADIO STUDENT AND
PRACTICAL OPERATOR

BY

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IN FOUR PARTS

Part One —Principles of Transmitting
Part Two —Principles of Receiving
Part Three—Vacuum Tubes and Continuous Waves
Part Four —The Practical Radio Operator

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Dr. Mahlon Loomis

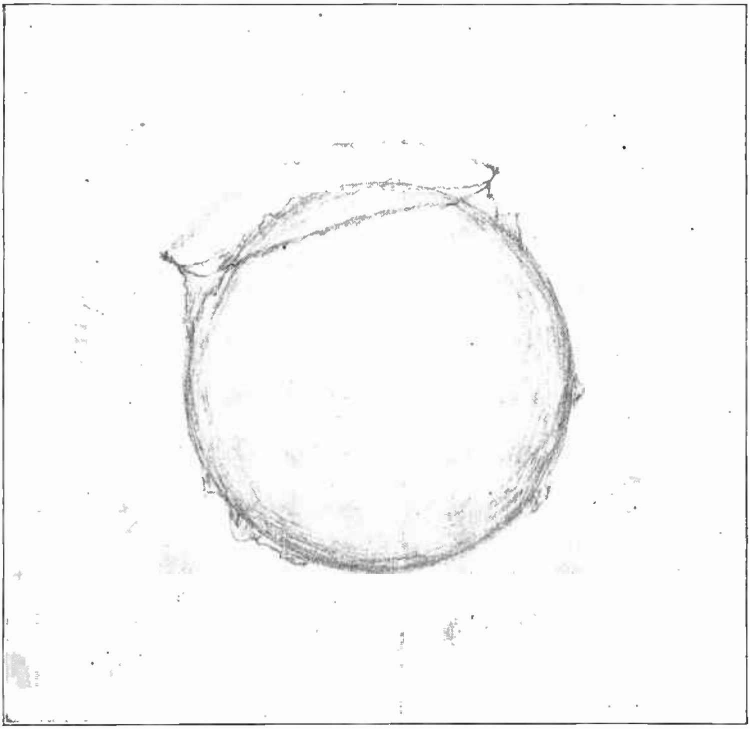
This book is dedicated to the memory of Dr. Mahlon Loomis, who, in 1865, sent the first aerial telegraph messages.

A word from Dr. Rogers.

"It was my pleasure to know Dr. Loomis in the early days when he was trying to convince a skeptical world of his new and wonderful discovery. So impressed was I that I went to see Professor Joseph Henry, then at the Smithsonian Institution, and unfolded to him Dr. Loomis' plans. *Time has vindicated this great pioneer in the art of wireless communication.*

Very sincerely yours,

J. HARRIS ROGERS,
Hyattsville, Md.,
July 13th, 1920."



Reproduction of drawing made in 1865 by Dr. Mahlon Loomis, showing his idea of how setting up "disturbances in the atmosphere" would cause electric waves to travel through the atmosphere and the ground, thus establishing wireless telegraph communication between two distant points. The aura around the earth represents what he termed the "static sea."

UNITED STATES PATENT OFFICE.

MAHLON LOOMIS, OF WASHINGTON, DISTRICT OF COLUMBIA.

IMPROVEMENT IN TELEGRAPHING.

Specification forming part of Letters Patent No. **129,971**, dated July 30, 1872.

To all whom it may concern:

Be it known that I, MAHLON LOOMIS, dentist, of Washington, District of Columbia, have invented or discovered a new and Improved Mode of Telegraphing and of Generating Light, Heat, and Motive-Power; and I do hereby declare that the following is a full description thereof.

The nature of my invention or discovery consists, in general terms, of utilizing natural electricity and establishing an electrical current or circuit for telegraphic and other purposes without the aid of wires, artificial batteries, or cables to form such electrical circuit, and yet communicate from one continent of the globe to another.

To enable others skilled in electrical science to make use of my discovery, I will proceed to describe the arrangements and mode of operation.

As in dispensing with the double wire, (which was first used in telegraphing,) and making use of but one, substituting the earth instead of a wire to form one-half the circuit, so I now dispense with both wires, using the earth as one-half the circuit and the continuous electrical element far above the earth's surface for the other part of the circuit. I also dispense with all artificial batteries, but use the free electricity of the atmosphere, co-operating with that of the earth, to supply the electrical dynamic force or current for telegraphing and for other useful purposes, such as light, heat, and motive power.

As atmospheric electricity is found more and more abundant when moisture, clouds, heated currents of air, and other dissipating influences are left below and a greater altitude attained, my plan is to seek as high an elevation as practicable on the tops of high mountains, and thus penetrate or establish electrical connection with the atmospheric stratum or ocean overlying local disturbances. Upon these mountain-tops I erect suitable towers and apparatus to attract the electricity, or, in other words, to disturb the electrical equilibrium, and thus obtain a current of electricity, or shocks or pulsations, which traverse or disturb the positive electrical body of the atmosphere above and between two given points by communicating it to the negative electrical body in the earth below, to form the electrical circuit.

I deem it expedient to use an insulated wire or conductor as forming a part of the local apparatus and for conducting the electricity down to the foot of the mountain, or as far away as may be convenient for a telegraph-office, or to utilize it for other purposes.

I do not claim any new key-board nor any new alphabet or signals; I do not claim any new register or recording instrument; but

What I claim as my invention or discovery, and desire to secure by Letters Patent, is—

The utilization of natural electricity from elevated points by connecting the opposite polarity of the celestial and terrestrial bodies of electricity at different points by suitable conductors, and, for telegraphic purposes, relying upon the disturbance produced in the two electro-opposite bodies (of the earth and atmosphere) by an interruption of the continuity of one of the conductors from the electrical body being indicated upon its opposite or corresponding terminus, and thus producing a circuit or communication between the two without an artificial battery or the further use of wires or cables to connect the co-operating stations.

MAHLON LOOMIS.

Witnesses:
BOYD ELIOT,
C. C. WILSON.

Photographic Reproduction of First Patent for Wireless Telegraphy issued in the United States.

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AUTHOR'S NOTE

THIS book is the result of successful teaching experience. *It is progressive in plan; and the beginner should not expect to understand the last chapters without having read the preceding ones.* Anyone mastering its contents should be thoroughly qualified to fulfil the duties of a practical radio operator on land or sea, and to pass any examination given by the government for the first-class commercial radio operator's license.

Wireless telegraphy, or radio as we prefer to call it, this being a more descriptive and less cumbersome name, marks the beginning of a new era of civilization. Radio communication has robbed the submarine of its terror and placed the scouting aeroplane on speaking terms with its base. The character of war has been changed. There can be no more surprise attacks. For on land and under the water and high in the air are prying ears, and little tongues of metal which speak on the vibrating breath of electricity; and *all the world* may hear.

Radio communication holds a unique place in the activities of mankind. It is a subject of the greatest popular interest; but is nevertheless based upon the profoundest of scientific principles. Students of radio should not be satisfied with merely a superficial knowledge of its operation.

Two distinct subjects must be mastered to qualify one for the duties of a practical radio operator, namely, the code and the "theory." The latter is covered in this text book. The code requires patient application; and for the attainment of the speed and accuracy necessary for obtaining the Government license as a first-class radio operator, it requires individual instruction. The code, and some hints regarding learning it, are given in the appendix.

MARY TEXANNA LOOMIS, *President*,
Loomis Radio College,
Washington, D. C.

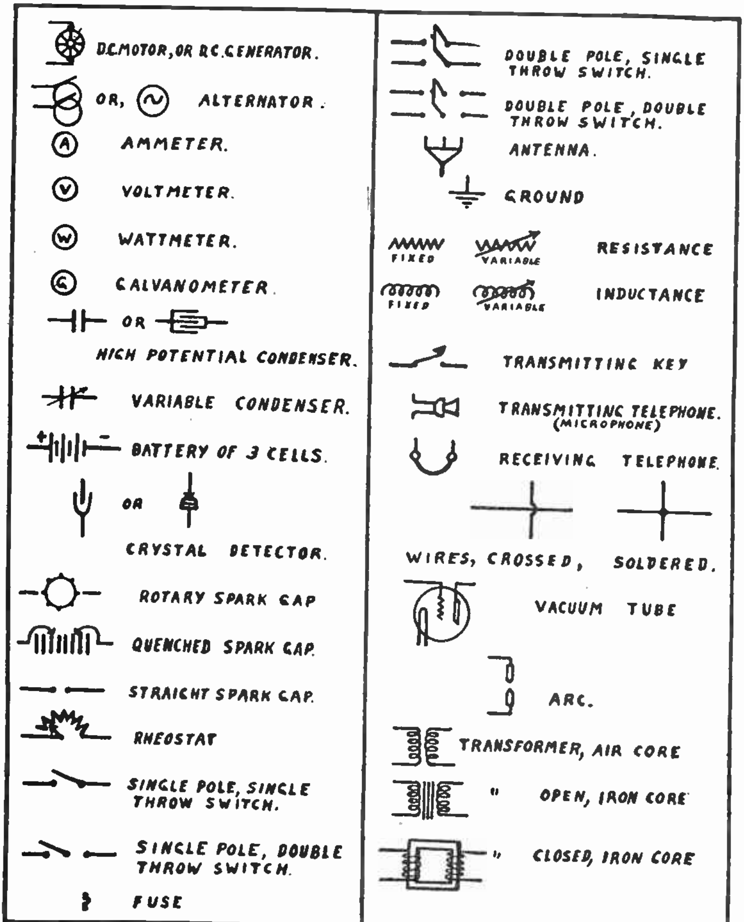


TABLE OF SYMBOLS.

PART ONE

PRINCIPLES OF TRANSMITTING

CHAPTER 1

History and Function of the Antenna

Properties of Electricity—Origin of Word Electricity—Dr. Mahlon Loomis's Early Aerial and Theory of Electromagnetic Waves and Wireless Telegraph Communication—Various Types of Antennæ and Materials Used—Antenna Insulators—Function of the Antenna

1. *Electricity is the motive power of all radio apparatus.* Although we are beginning to understand some things about what electricity is, we can only prove its existence by its *effects.* The best known effects are heat and light. Magnetism is also an important property of electricity, and is the basis of all electric power machinery. There is a pronounced chemical action to electricity when it is given appropriate vehicles, and this is the principle on which wet cells, dry cells and storage batteries are based. Besides these, electricity, under certain conditions, will *radiate vibrations* which are generally called *electromagnetic waves;* and it is these waves that are used in communicating through space. Because we employ electricity in various ways in different parts of the apparatus used for creating the electromagnetic waves, we can only gain an intelligent understanding of this process by taking the various effects of electricity singly and giving them careful consideration one at a time; and by thoroughly studying their functions in their various practical applications.

2. Electricity, as produced by rubbing amber, was known to the cultured races of remote antiquity. The word comes from the Latin *electrum*, and Greek *elektron,* meaning amber. In 1600 the first important book on the subject, entitled De Magnete, was published by Wm. Gilbert. The first known electrical machine was invented in 1672 by Otto von Guericke, of Amsterdam. It consisted of a sulphur ball revolved on a shaft by hand. After this was revolved for some time it was possible to detect the presence of a charge of electricity on the ball by passing the hand over it. The famous experiment of Benjamin Franklin, when he attached a brass key to an elevated kite and demonstrated some of the effects of electricity, was in 1752. There were many early attempts to

invent some method of wireless telegraphy employing electricity as the motive power. In 1795 a Spanish scientist named Salva appears to have succeeded in transmitting messages under water by the conduction of a direct electric current. In 1842 Samuel Morse did the same thing with slightly different apparatus. Under water seems to have been the first idea in connection with wireless telegraphy. A Scotchman, J. B. Lindsay, in 1860, secured a patent for a somewhat similar system of telegraphing without connecting wires, by which he was able to "send messages by the aid of artificial batteries, short distances, near Dundee." In 1862 John Haworth patented a method of conveying electric signals, "without the intervention of any artificial conductor." This also conveyed the signals under water or earth, by means of buried copper and zinc plates and buried coils supplied with weak battery power.* At about the same period in history several other men are on record as having accomplished more or less along these lines, among whom were Prof. Joseph Henry, of the Smithsonian Institution, Messrs. Vail and Rogers, Professor Trowbridge, of Harvard University, and Alexander Graham Bell. That none of these persons conceived the idea of an antenna, or of radiated electric waves, is quite certain. A. T. Story, an eminent English author, in his "Story of Wireless Telegraphy," says that "With the experiments of *Mahlon Loomis* we *first hear* of the application of vertical conductors, or *antennae*, as they are sometimes called, for the transmission of signals to a great distance."

3. Dr. Mahlon Loomis's antenna, or aerial, was first heard of in 1865. Dr. Elisha Loomis, of Berea, Ohio, states that in 1866 he "demonstrated it beyond controversy, in the presence of eminent scientists and electricians, by sending many messages between two stations in Virginia, eighteen miles apart, and at sea, on Chesapeake Bay, between two ships two miles apart." In 1872 he obtained a patent for his system of "aerial telegraphy," employing an "aerial" which he used to radiate or to receive "pulsations" caused by producing a disturbance in the "electrical equilibrium of the atmosphere." Mr. Conger, in a long speech in Congress on May 21, 1872, relative to the "Loomis Aerial Telegraph Bill," requesting an appropriation of $50,000, which had been introduced in 1869, described the principle of operation of Dr. Mahlon

*See British patent number 843 of 1862, to John Haworth.

practically all idea originated with Dr.

find in the Washington *Chronicle* of November 1, 1872, that Dr. Mahlon Loomis conducted his experiments with "kites covered with fine light gauze of wire of copper, held with a very fine string or tether of the same material, the lower end of which formed a good connection with the

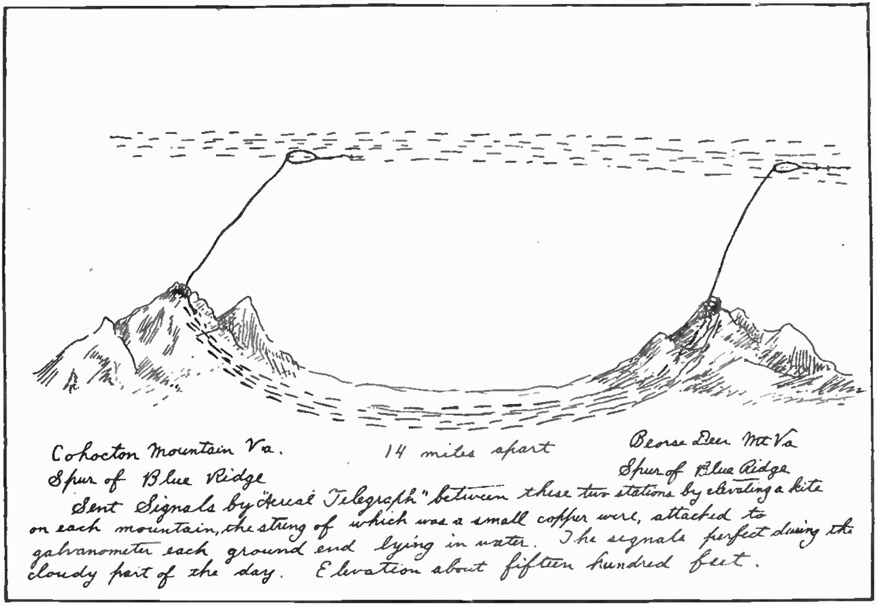


Fig. 1. The First Antennæ.
(Reproduction from Dr. Mahlon Loomis's sketch, 1865)

with
common use today
the *inverted "L,"* on account
number of wires held parallel to each other
suspended horizontally between two masts or towers, with a "lead-in" at one end. This was invented by *Marconi* in 1905. A variation of this is termed the "T." It is the same with the exception of having the lead-in attached to the center instead of at one end. Another form is built around one central pole or tower, and is called the *"umbrella antenna."* It is used extensively in Germany for high-powered transmission, and is occasionally seen in connection with portable radio apparatus in military work. Some high-powered stations are equipped with antennae consisting of wires arranged in the shape of a *fan,* which is a very efficient arrangement, but rather expensive. In comparatively recent developments an antenna in the form of a *loop* has been found useful for special purposes. It is used almost exclusively for receiving, not having sufficient radiation for practical transmitting to any great distance.

6. It is possible to make use of many other contrivances for the purpose of receiving electromagnetic waves, but for transmitting, a properly installed antenna is generally necessary. It has been found that a tree can be used for a receiving antenna, preferably an oak, by attaching a lead-in wire to the trunk of the tree, and aeroplanes frequently employ a single hanging wire for an antenna, using some part of the rigging of the plane in place of the ground. In *Dr. Rogers'* underground wireless telegraphy he makes use of buried wires for antennæ, thus picking up or transmitting electromagnetic waves through the ground instead of through the space above the ground. Thus the word antenna, from

wire. This
of about number 18
and, enameled copper wire, about
popular. The enamel prevents corrosion.

8. As radio communication is carried on in dialogue fashion, it is necessary to have two distinct kinds of apparatus, one for transmitting and the other for receiving. These are generally installed in such a manner that the same antenna will suffice for the use of either, the change from one to the other being accomplished by means of a switch known as the *antenna change-over switch*. In order to form a conductor for the passing of electric current, it is necessary that the antenna have a ground connection. In the construction of transmitting and receiving apparatus this is provided for in such a way that the current, in seeking the ground, passes through parts of the apparatus. All radio installations, where a transmitter is included, have installed in connection with their change-over switch, what is known as a lightning switch, for protection from damage by lightning in electrical storms. It consists of a simple switch attached so that by throwing it in one direction the antenna is connected directly to the ground and by throwing in the other direction the antenna is connected to a second switch inside of the station, which in turn provides for changing from transmitter to receiver, and vice versa.

9. To prevent escape of current down the masts or towers, insulators are placed between the wires composing the antenna and the spreaders, or in some cases only between the spreaders and the pulleys. The lead-in wire is also carefully protected at its entrance to the building or cabin by an insulating tube. These may be composed of various ma-

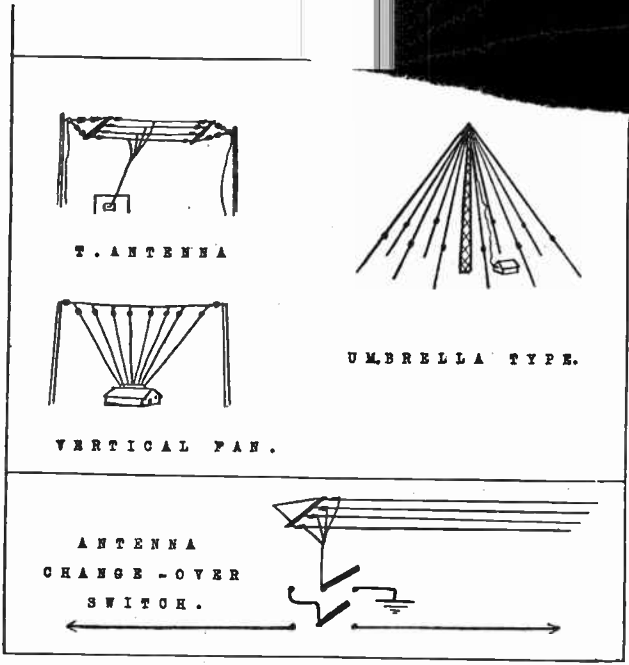


Fig. 2. Various Forms of Antennæ, and Simple Change-over Switch with Lightning Switch.

sometimes seen, but the type most employed is of a material similar to porcelain. When insulators are made to stand the strain of the weight of wire, they are usually called "strain insulators," one well-known make selling under the name of "Electrose strain insulators." Most of these insulators are corrugated, or ribbed. This is for the purpose

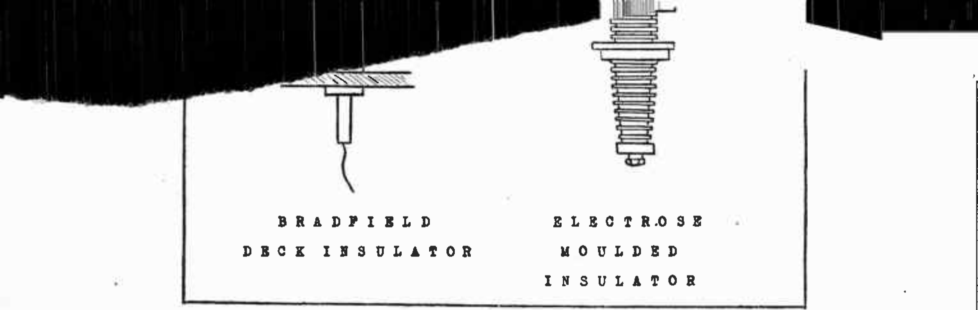


Fig. 3. Lead-in Insulators.

10. A recent type of antenna is known as the "cage" antenna. (See Fig. 5.) Some practical operators have been known to refer to this as a "sausage." It may be suspended vertically from a horizontal supporting wire, or the "cage" may be stretched horizontally between two masts and have a lead-in from either the center or from one end. This type has several advantages. It requires little space, which is valuable on board ship; and if one of the wires should be damaged, the remaining may still be used.

Fig. 4. Electrose Strain Antenna Insulators.

11. A definition of the function of the antenna is as follows: *The function of the antenna is to radiate energy in the form of electromagnetic waves for the purpose of transmitting messages, and to absorb energy from passing electromagnetic waves sent out by a distant transmitter, for the purpose of receiving messages.*

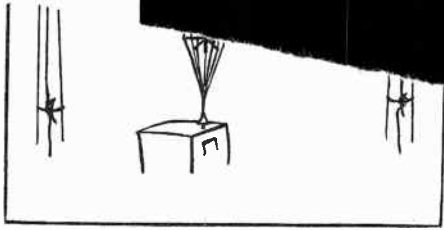


Fig. 5. Cage Antenna.

12. When we see an antenna swung between the masts ot a ship we know that the lives of its passengers and crew are protected by radio communication. When we see high towers, holding aloft delicate spans of wire, we have visible proof of the location of a high-powered radio station. The size and type of antenna used in each case depends upon the purpose for which it is to be used, the power which it must carry, and the space available.

... key
... was included in
... by *Samuel Morse,* although
...ed and used for several electrical ex-
...before that date. It is known as the *Morse key.*

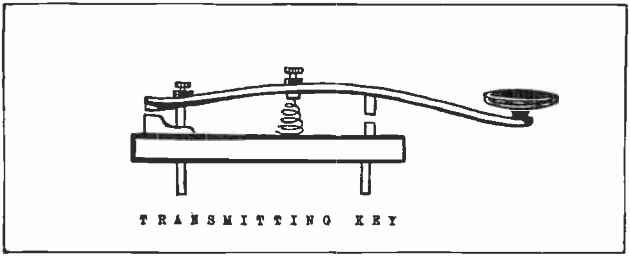


Fig. 6. Morse Key used for Transmitting.

14. The contact of the key is made through two small metal points controlled by a spiral spring. When the disc is depressed by the operator's fingers, these points touch each other; and when the operator releases the disc, the spring throws the disc upward, separating the contact points. There are some variations of this key, but the principle is always the same. By depressing the disc for a short period of time, the electricity is allowed to pass through the contact points for a short time, the antenna radiates electromagnetic waves for a short time, and a short sound is produced in the telephones of a distant receiving set. This is called a "dot." Of course, then, when the key is pressed for a somewhat longer time a longer sound will be heard in the receiving telephones, and recognized by an operator who is listening in as a "dash." So, by means of the key for the speaking

15. In order to [illegible]
must be some source of pow[illegible]
waves may be produced and caused [illegible]
antenna. There are several ways of obtaining [illegible]
purpose. Also the characteristics of the electromagnetic waves which are radiated differ according to the various methods used in producing them. From one type of transmitting set the waves come in at the receiving station in even vibrations of continuous amplitude. These are called continuous waves, or undamped waves. From another kind of transmitter the waves intercepted at the receiving station will come in groups, each group consisting of a number of waves of gradually decreasing amplitude. These are known as damped waves. Receiving sets have to be adapted to the reception of these various types of waves.

16. In the early days the high-powered electrical machinery in common use today was not available for operating the wireless-telegraph transmitter. Chemical cells were used extensively in these experiments. One of Dr. Loomis's ideas was to gather electric power from the upper strata of the atmosphere by use of his kite aerials, and by some other means with which he was experimenting, consisting of some arrangement which included "gilded balloons" carrying mercury lamps. He did succeed in transmitting intelligible messages over a distance of eighteen or twenty miles, using electric power obtained solely from the atmosphere for this purpose. This appears to have been about the extent of the successful use made of atmospheric electricity up to the present time. We cannot say that this idea may not in some future day be made to serve mankind on a great scale. The following ex-

tracts are from a lecture delivered by Dr. Mahlon Loomis in Philadelphia, in 1872: "Where do we look for the greatest display of might and power but to the atmosphere with its restless and appalling thunderbolt, coming unforeseen and shooting at fatal random. In all nature nothing is so powerful, nor so terrible because powerful. And yet this great element goes to utterly idle waste, often causing death and devastation; strange to say no attempt is ever made to utilize this immense wealth to the purposes of man. Its volume is unlimited and its working power inexhaustible and without diminution. The great electrical ocean, slumbering with giant power, untold wealth and willing aid, waits but the proper sluiceways or conducting channels to illuminate, and to drive the wheelwork of the world. But in its unclaimed usefulness, its wild and random freaks only cause universal terror."

17. At the present time electric power for transmitting radio messages is generated by artificial means. Storage batteries are carried on board ships in sufficient number for operating the transmitting apparatus for a short time in case of emergency. But the power is generally obtained from electrical machinery, which operates on principles based on the laws of magnetism. These machines may produce either direct current or alternating current. Direct current is just what its name implies. It proceeds in the same direction continuously. This is also the kind of current produced by the various chemical cells. Alternating current continually reverses its direction at regular intervals. Direct current is sometimes likened to a river flowing, and alternating current to the rising and falling tides. In order to produce electromagnetic waves and to radiate them from the antenna, it is necessary to employ alternating current. Direct current forced directly onto the antenna will not produce the waves. Some types of apparatus employ a high-powered machine which produces alternating current which reverses its direction at an extremely high rate of speed, or high *frequency*. And this machine is connected so that these high-frequency alternations pass directly to the antenna. This produces the waves which do not decrease in amplitude. Other transmitters use an alternating current generator of lower frequency, and several other pieces of apparatus, including transformers and condensers, connected between the alternator and the antenna. These are known as "spark

sets," because when the key is pressed, the electricity is made to jump across a space called a gap, at which instant it causes a "spark." The waves radiated by this type of a transmitter are the kind which decrease in amplitude in each group.

18. A *generator* is a machine for producing electric power; and may be driven by either mechanical power, such as a water wheel, gasoline or steam engine, or by a crank turned by hand. Or it may be driven by an electric motor. A generator which produces alternating current is called an alternating-current generator, or *alternator*. A generator which produces direct current is called a direct-current generator.

19. A *motor* is a machine for producing mechanical power and is driven by electricity. The "spark set," which for several years was the standard type of transmitter on ships, usually includes an alternator and motor coupled together in one case. This is known as a *motor-generator*. It is driven by direct current which is obtained from the "ship's dynamo," a d.c. generator supplying current for all purposes on the vessel. The term *dynamo* is applied in a general way to all electrical machines operated on the principles of magnetism, and may refer to any kind of a generator or motor. However, among radio operators at sea, the dynamo is understood to be the one referred to above.

20. Definitions—

A dynamo is a machine used to convert mechanical energy into electrical energy, or electrical energy into mechanical energy;

A generator is a mechanically driven machine for producing electrical energy;

An alternator is a mechanically driven machine, or generator, for producing electrical energy in the form of alternating current;

A motor is an electrically driven machine for producing mechanical energy.

21. The processes by which these machines produce mechanical or electrical energy, and by which direct current or alternating current is produced, are exceedingly interesting, and at first seem somewhat complicated, although the principles are quite simple. Before making a study of the de-

tails of the various types of electrical machines, it is necessary to master the laws of *magnetism* and the *laws controlling the performance of electric current.*

22. Receiving sets vary mostly in regard to the *detector* employed with them, which may be of the vacuum-tube variety, now familiar to the general public, or of the simple crystal type, which has been in use much longer than the tube. The detector, of whatever kind, is used to "detect" the waves which carry the message. In a general way, it may be stated that when a distant transmitter is caused to emit electromagnetic waves which vibrate at a certain rate and you succeed in adjusting a receiving set so that it is possible for it to vibrate at about this same rate, you will "pick up" the waves radiated by the transmitter.

CHAPTER 3

Magnetism

Lodestone—Magnets—Magnetic Lines of Force—Meaning of Electric and Magnetic—Laws of Magnets—Earth Magnet—Compass—Molecular Theory of Magnetism—Right-Hand Rule—Rule for Polarity of Solenoid—Electromagnetism

23. Crabb's Synonymes is authority for the statement that the words *electric* and *magnetic* originally meant the same, viz., "the *attractive power* associated with certain substances under certain conditions." The elektron was the amber of ancient Greece, which would attract some articles after being rubbed. The magnet was the lodestone, or natural magnet, found in the earth near the town of Magnesia, in Asia Minor, about 480 B. C. "But as the science of electricity has developed, *magnetic* has been associated with the properties of a *magnet* and *electric* with a *force* or *current* existent or generated under certain conditions. When used figuratively, *electric* refers to the *swift and thrilling quality of electricity, magnetic* to the quality of *attractiveness* associated with the mysterious thrill of *electric force.*"

24. No one knows for certain just how this lodestone, or magnesian stone, came to be magnetized; but it was undoubtedly due to the influence of the earth's magnetism in some way, probably in connection with an earthquake or a volcanic eruption which caused a severe jarring of some iron ore. It is now found in many parts of the world, one variety, consisting of pure iron oxide, being known as magnetite. It is possible to make an artificial magnet from a piece of the right kind of steel by rubbing it with a natural magnet until the steel has become impregnated with magnetic force. Magnets are also made by subjecting pieces of iron or steel to the influence of an electrically charged wire. The process by which magnetism passes from one magnet to another or from a charged wire to a piece of iron or steel, is called *magnetic induction.*

25. Everyone is familiar with the action of a magnet, how it will attract needles or steel filings, and cause them to adhere to it until removed. While iron or steel, in an unmagnetized state, does not attract other iron or steel, it does attract magnets. A compass needle will turn toward a piece of iron or steel nearby and be deflected from its natural position of pointing north and south.

Upon studying the action of a bar magnet, we find that its attraction is much stronger at the ends than at the sides, and that two magnets if placed together in one way will repel

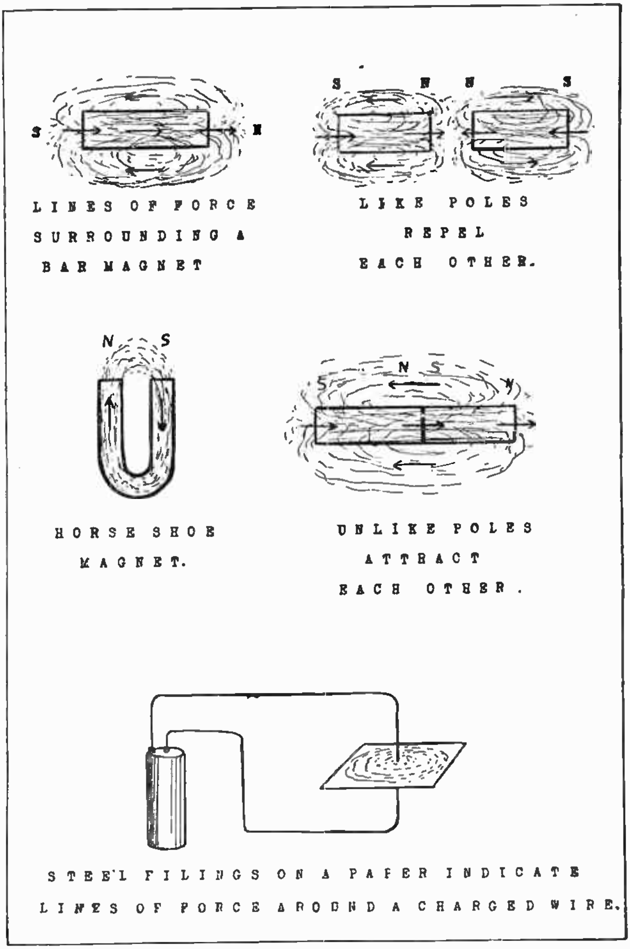


Fig 7. Lines of magnetic force surrounding magnets and around a charged wire.

each other and if placed together the opposite way will attract each other. This is understood after proving by a few simple experiments the direction of the lines of force within and surrounding the magnets. We find that a magnet has constantly passing through it a magnetic impulse, which we call *lines of force*, or *magnetic flux*, or *field*. The lines of force are believed to move through the magnet, out at one end, through the space immediately surrounding the magnet, and to return to the magnet at the other end. To prove this, take a magnet and lay over it a piece of window glass and gently sift fine steel filings upon the glass. You will observe the gradual appearance of the "magnetic map" of the magnet, as the steel filings become magnetized by induction, and arrange themselves to conform with the magnetic flux of the magnet. The end from which the force moves outward is called the *north pole* of the magnet, and the end to which it returns is called the *south pole*. A small pocket compass will indicate the direction of the outward and inward lines of force of the magnet. The north pole of the compass needle will seek the south pole of the magnet, and vice versa. Two north poles, if magnets are placed together in this relation, will repel each other because their lines of force are in opposing directions. The south poles will also repel each other, but with less force. On the other hand, two opposite poles will attract each other, because their lines of force are in the same direction, and the consequent attraction is for the two to unite and make one continuous magnetic flux. *The law of magnetic attraction and repulsion is: like poles repel, and unlike poles attract.* Some physicists look upon the magnetic lines of force as simply a condition of strain, which is not moving. The majority, however, seem to think of them as moving. One refers to them as "Similar to stream lines in a moving fluid."

26. When a bar magnet is suspended by a silk cord, or mounted on a pivot so that it is free to move, it will immediately take a north and south position, thus proving that the earth itself exhibits properties of magnetism, and has magnetic polarity. In a general way, the earth may be said to be a large spherical magnet. However, due to iron deposits in various localities, its magnetism is far from uniform, and due to its shape the magnetic field at the poles is not as much stronger than at other points as is the case with the bar magnet. Many interesting theories and discoveries regarding the earth's magnetism have been made; but there is still a great deal to be learned about it. The pole of the magnet which is known as its *north* pole will

invariably seek the *earth's magnetic pole of the opposite polarity.* This is in the northern hemisphere, a little to one side of our geographic north pole. Hence the south magnetic polarity of the earth corresponds to its geographic north pole. A magnetized steel needle, if suspended horizontally from the center, will dip towards the earth. At the north or south magnetic pole of the earth the needle will dip at an angle of 90°, or stand vertical. At the magnetic equator it remains horizontal.

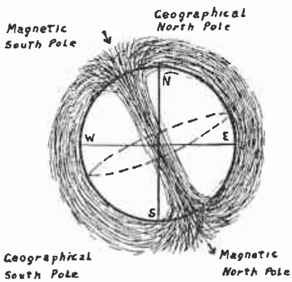


Fig. 8. The Earth Magnet.

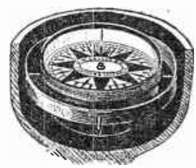


Fig. 9. Mariner's Compass.

By mounting a small needle-shaped magnet over a graduated scale, so that it revolves on a jeweled bearing, we make what we call a compass. We move the scale around until the N, meaning north, on the scale, is under the north pole of our magnetic needle, and thus locate the geographic direction of north, making allowance for the variation of the magnetic meridian from the geographic meridian. The mariner's compass, based on the same principle, is somewhat more elaborately constructed. The card marked off in "points of the compass" is fastened to the needle and moves with it, the north point on the scale always pointing north. This is mounted on jewel bearings inside of a bowl, on the inner surface of which certain points of the compass are marked. A line indicating the direction of the ship, and known as the "lubber's line," is also marked on the inside of the bowl. By turning the ship and comparing the "lubber's line" and the points of the compass, navigators are enabled to steer their course. The bowl compass is mounted on gimbal bearings, which keep it level at all times, regardless of the roll of the ship. Recent research has shown that navigating by means of the chart and compass is not as safe as had been supposed, on account of changes in the earth's magnetic flux and possible errors in the compass reading due to the attraction of metal on the ship.

27. When a magnet is broken or cut in two or more pieces, each piece will exhibit all the properties of a separate magnet, having its individual poles exactly like the larger one from which it was made. This can be accounted for by what is termed the molecular theory. It is assumed that the molecules, or infinitesimal particles of matter composing the metal are more or less permanently magnetized; that in a non-magnetic piece of metal these molecules are in such relation to each other that no tension or magnetic strain is created. But when these molecules are subjected to the attracting and repulsing influences of a magnetic field surrounding either a permanent magnet or an electrically charged coil of wire, these molecules assume positions corresponding to the lines of force of these magnetic influences, and a north and a south pole appear.

Fig. 10. The Position of the Molecules in an Unmagnetized Piece of Iron or Steel, or of Steel Filings in a Glass Tube.

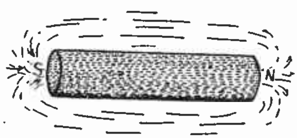


Fig 11. Position of same Filings, or Molecules, as in Fig. 10, when Magnetized.

28. The capacity for yielding to a magnetic influence depends on what is called the *permeability* of the material to be magnetized or its degree of resistance to molecular changes. The capacity for holding magnetism after the magnetizing influence is removed is known as *retentivity.* When magnetized to the limit of its capacity it is said to be magnetically *saturated.* Soft iron is quickly magnetized under electrical influence, but loses considerable of its magnetism immediately upon removal of this influence. Hard steel accepts magnetic lines of force slowly but retains them indefinitely—permanently, or at least for several months or years. These

facts affect the choice of materials used for magnets, according to the particular use for which they are required. Where a *permanent* charge of magnetism is desired, the hard steel is used, and where a quick magnetic response to electrical influence is wished, soft iron is used. There are other substances which can be slightly magnetized, or will be attracted slightly by an iron or steel magnet. Among these are nickel, cobalt, antimony and chromium. Copper, gold, lead and platinum will not respond even slightly to magnetic attraction, and may be termed non-magnetizable substances. Iron and steel are used exclusively in practical electrical work.

29. It is easily proved that *magnetic lines of force exist around a wire through which an electric current is moving.* If a wire be connected to a chemical cell, so that current flows, and a small pocket compass held over the wire, the needle of the compass will turn at right angles to the wire, with the north pole of the needle pointing in the direction of the magnetic lines of force around the wire. *By coiling the right hand around the wire with the palm upwards, and the fingers pointing in the direction indicated by the north pole of the compass, or in the same position with the back of the hand over the wire if it is a high-tension line, the negative end of the circuit is indicated by the thumb.* This is known as the *right-hand rule for the direction of current through a conductor.* Figure 12 illustrates the lines of force swirling around a charged wire, while looking at the *positive* end of the wire. *Tracing the movement of electrons from negative towards positive, the lines of force are counter clockwise to this movement.* (See paragraph 36.)

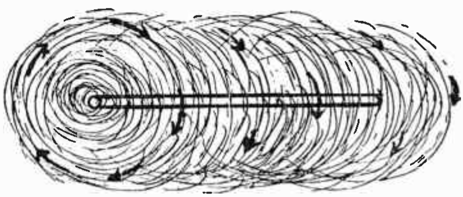


Fig. 12. Lines of Force Around a Charged Wire.

30. When we coil a wire it is called a *helix.* When the helix is charged with electric current it is called a *solenoid.* A solenoid unites the lines of force around the individual turns of wire composing it, and a complete magnetic flux is produced, similar to that around a magnet. When an iron

core is inserted into the solenoid, it provides a path for the lines of force passing through the center of the coil, and we have a temporary, or *electro magnet.*

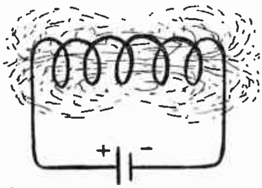


Fig. 13. Magnetic Flux of a Solenoid.

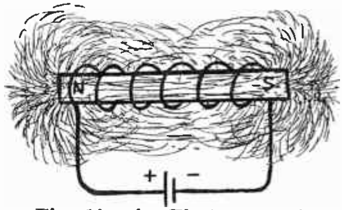


Fig. 14. An Electromagnet.

31. By use of the *magnetic action of solenoids,* magnets are produced which are moving a large share of the world's work. *The telegraph sounder* which clicks every minute of the day and night with important messages is the simplest thing imaginable when the principles of magnetism are understood. The *polarity* of the magnet within the solenoid depends upon the *polarity of the solenoid.* The lines of force pass along the coil and form magnetic lines of force from one loop to another, until at the last loop they enter the space in the center of the coil and pass back through it. Therefore, the polarity of the coil depends upon the *direction of the winding*—the direction of the current being the same. This can be determined by the *right-hand rule for the polarity of a solenoid, as follows: Grasp the coil with the fingers turned in the direction of the winding, when looking into the coil from the positive end of the source of current. The thumb will then point to the north pole of the solenoid, which will be nearest to the negative end of the circuit if the coil is wound clockwise, or nearest the positive end of the circuit if the coil is wound counterclockwise.* The telegraph sounder is constructed with two soft iron cores inserted in two solenoids which are wound so as to produce magnetic poles of opposite polarity. When the key is pressed the current sets up magnetism which magnetises the iron cores, and a flat iron bar horizontally attached to a brass lever is attracted to the magnets thus formed, and by striking the brass screws against the brass lever a sharp click is made. It would work with only one magnet, but by the use of two of opposite polarity, we have practically the same thing as a horseshoe magnet, and a much stronger attraction for the iron bar, and a louder click.

The familiar *buzzer* consists of two small electromagnets placed in the same relation as those of the sounder. In this the vibrator consists of a thin steel spring mounted over the cores and making and breaking contact to the circuit as the spring is attracted and then released due to the break thus caused. (See paragraph 263 for illustration.)

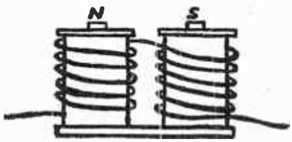


Fig. 15. Electromagnets of Telegraph Sounder.

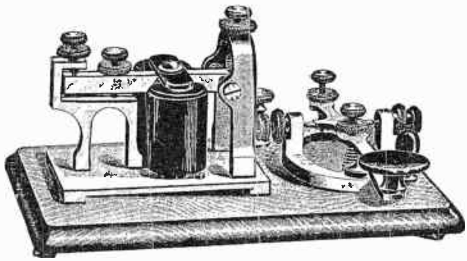


Fig. 16. Morse Telegraph Sounder.

32. By placing two or more electromagnets of *opposite polarity* inside of an iron frame, and placing a separate coil between them so that it comes in inductive relation with the lines of force, we cause the separate coil to revolve, and we have a *motor*. By different connections to practically the same arrangement, and revolving the separate coil mechanically, we have a *generator* which will give us electric energy in the form of current. The magnets used in these machines usually retain some of the force induced into them after the current is shut off from the solenoid; and this is, in some cases, an important part of their mechanism. Magnetism retained in this way is referred to as *residual magnetism*. Enormous electromagnets, suspended from cranes, are used for lifting and moving heavy loads of iron or steel. The load will adhere to the magnet as long as the current is turned on, and can be dropped by opening the switch. Permanent magnets which are used commercially are manufactured by placing pieces of steel in inductive contact with the

magnetic force of electric current, under proper conditions, until they have received a permanent charge. They are employed in electric meters, in telephones, certain types of generators, etc. Some of the magnets are straight bars and some are horseshoe in shape. A horseshoe magnet provides a circuitous path for the lines of force, and is better suited for some purposes than a straight magnet. When not in use a straight rod of iron should be placed across the open end of the horseshoe to completely close the magnetic path. This is known as the *keeper*. It keeps the magnetism in the horseshoe, and greatly lengthens the life of the magnet. Good magnets require care, and should not be heated or jarred.

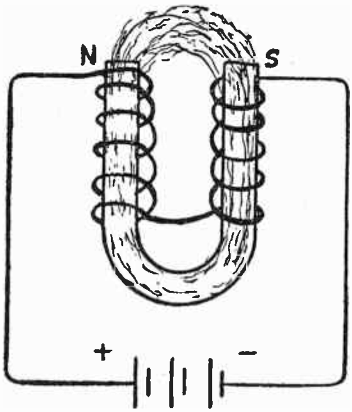


Fig. 17. Horseshoe Electromagnet.

33. Magnets are occasionally used which are constructed so as to overcome, so far as possible, the magnetic influence of the earth upon them. They consist of two or more magnets rigidly attached to a stiff rod, which prevents their turning under the power of attraction and repulsion. These are known as *astatic magnets,* and their principal use is in certain types of meters. In many cases it is found an advantage to use a magnet composed of several thin layers of steel pressed together, or of a bundle of fine iron wires, instead of the solid material. These are called *laminated* magnets. They are stronger than magnets composed of one piece of material. The reason for this is believed to be due to the

magnetism which is artificially induced into them being stronger nearer the surface of the magnet than through the center. Thus, if we provide more surface, we have more magnetism. It also reduces the tendency for little stray currents, or *eddy currents*, to move in the metal, when the magnet is energized by a solenoid, and thus reduces heating of the metal which causes loss of energy. Laminations also reduce *heat* in *electromagnets* due to *hysteresis*, which is the *opposition to a change of the position of the molecules in the metal, when the current in the solenoid is alternating current*, constantly reversing the polarity of the solenoid, and consequently of the magnet which is its core.

34. Magnetic lines of force can pass through all substances—glass, rubber, metals, etc. They cannot be prevented from passing through such materials. A piece of soft iron, however, will absorb them to a certain extent, so where it is desired to prevent magnetic lines of force from penetrating some electrical device, a *magnetic screen* consisting of pieces of soft iron is sometimes arranged so as to surround the working parts of the apparatus.

The effect of magnetism upon iron is being studied in the laboratories of the General Electric Company, by means of an amplifying device and a loud speaker. When a magnet is placed near a piece of iron which is connected in this testing circuit, a distinct *roar* is heard from the loud speaker. It may possibly be proved later that this has some connection with the change in the relation of the molecules of the iron.

CHAPTER 4

Static and Dynamic Electricity

Definitions of Static and Dynamic Electricity—Electron Theory of Electric Current—Reference to Methods of Producing Electric Current—Conductors and Insulators

35. *Electricity* may be divided into two general branches, although it is so divided on account of the action of it in these different phases, rather than on account of any difference in the electricity itself. We must assume that electricity is always the same thing. The two branches are *static electricity* and *dynamic electricity*. *Static electricity* is generally defined as *electricity at rest,* or more definitely, it is that electricity that is present in the atmosphere and presumably, in small quantities, in everything in the universe. Strictly speaking, electricity in any form never seems to be exactly "at rest." *Dynamic electricity* is electricity in action, this term generally referring to electricity that has been generated by artificial means.

Static electricity, when afforded the proper conducting path and propelling force, may become dynamic, and *dynamic* electricity may become temporarily static, when stored, if only for a fraction of a second, in any object where it remains in a state of strain and ceases to travel along a conducting path.

36. Numerous theories concerning electric current have been advanced at various times, only to be discarded later on. The modern one is known as the *electron theory*. The premise of this is that all material things contain microscopic particles, much smaller than atoms, having a negative charge. These particles are called electrons, and it is supposed that their electric charge is in some manner produced by the vibrations radiated from the sun. Each atom is composed of a great many negative electrons, which it is believed are held together by a positive nucleus. Some of the electrons adhere closely to the nucleus and others, more loosely attached, may be jarred free. The latter are known as "free electrons," and it is the movement of these through conductors, probably from one atom to another atom, that is now known to produce an electric current. In different ways, some objects come to have an accumulation of more negative electrons than others. Those which have the greater number are said to have a *negative* electric charge, while those in the opposite condition are said to have a *posi-*

tive charge. As there is a natural tendency towards equilibrium, the positively charged body will attract the negative body, and if two bodies having opposite charges of this kind are connected with a suitable conductor, the rush of negative electrons from the spot where they are in excess to the point which lacks a normal number of them results in heat and light and magnetism, and we know that we have electricity in an active form in the conductor. The movement may take place between the clouds and the earth, and we have what we call a flash of lightning. One might think of the attraction of the positive condition for the negative electrons as being somewhat similar to a state of vacuum, or partial vacuum, which has a *suction* effect upon the negative electrons; and the *force* of this kind of an attraction is strongest at the positive point, where the lack of negative electrons is greatest. *In an electric circuit, then, the electrons move from the point which has been named negative to that which we call positive.* There must be more electrons at one end than at the other, or there will be no current. As there seems to be no reason for believing that a "current" could be "flowing" *against* this movement of electrons, we must assume that *it is the movement of the electrons which is the current,* hence the current must be in a direction from negative toward positive in the circuit. There will also be attraction between two negatively charged bodies, if their charge is not equal, a movement of electrons taking place from that point having a stronger negative charge towards a point having a weaker negative charge. Before the electron theory was known, it became the custom to speak of the current as flowing from the positive to the negative of a circuit, which appears to have been an error. Some confusion still exists, due to the old rules being worded in accordance with the old notion of the direction of the current. In diagrams representing electric circuits it is customary to indicate the negative charge by a minus sign, and the positive state by a plus sign.

37. *Static electricity* can be generated, or accumulated from the atmosphere, by friction. Simple examples of this are that a hard rubber comb, after being run vigorously through the hair, or a piece of glass rubbed briskly over a piece of silk, will pick up small bits of paper. Static machines are built on this principle; but electricity in this form has few practical applications, and is confined almost en-

tirely to medical appliances. *Dynamic electricity* can be produced in three ways—by *mechanical action,* by *chemical action,* and by *thermal action.* The thermal method has at the present time only a limited practical value. It is accomplished by applying heat to the point of contact of two bars of unlike metal, antimony and bismuth or copper and iron, that are placed across each other. Also, the heating effect of electricity in two wires when crossed is made use of, principally in certain kinds of meters. Mechanical action is invariably employed in connection with an application of the *laws of magnetism,* and includes all forms of electrical machinery. *Chemical action* is the principle on which all forms of batteries are based.

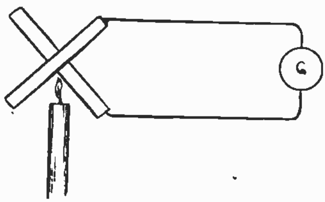


Fig. 18. Galvanometer in Circuit with Thermal Junction.

38. In order to make use of electricity in current form, it is necessary that it be provided with suitable conductors. A *conductor is a substance or object which does not resist the flow of electric current, or which resists it only slightly.* Materials differ considerably in this regard, some being better conductors than others. Silver is probably the best conductor of electric current, but on account of its great expense and poor wearing qualities it is not suitable for general use in commercial and electrical work. Gold is an excellent conductor, but naturally it is not employed to any great extent. Copper, bronze and brass are the next best conductors and are used extensively in different parts of electrical apparatus. Other substances, all used in some ways in electrical work as conductors, are aluminum, zinc, iron, lead, mercury, carbon and platinum.

39. While it is necessary to provide a conductor for the passing of electric current, it is also necessary to provide in

certain places a material which will not conduct electricity. *An insulator is a substance which prevents the flow of electric current.* It is by the intelligent use of insulators that the electricity flowing through the conductors which we use can be handled and controlled. The materials most commonly used for insulators are porcelain, rubber, mica, ebonite, glass and air. Oils, shellac, varnish, asphaltum, wool, silk, cotton, resin, paraffine, paper, asbestos and slate are also insulators of more or less value and used in certain places for insulating purposes. While we call these materials insulators we know of no substance through which an infinitesimal amount of current does not pass.

40. Where any great amount of power is desired the dynamo is used, because it is the most convenient and efficient method of procuring current in large quantities. The chemical method of producing electricity is employed where a weaker current is all that is required, such as for door bells, laboratory work, etc., or where a large amount is required for only a short time. The dry cell is a familiar example of the chemical production of current on a small scale, and has the advantage of freedom from grease and moisture. The laws of the *electric circuit* are best studied in their simplest application first. After the fundamental principles are understood, a number of combined circuits are not confusing. The simplest form of an electric circuit is produced by attaching a loop of wire to a simple chemical cell.

CHAPTER 5

Chemical Cells and the Electric Circuit

History of Chemical Cell—Constuction and Operation of Wet and Dry Cells—Various Makes of Wet Cells—Effects of Cells in Series and Parallel—Connections to Power Circuits

41. The *chemical method of producing an electric current* is believed to have been discovered in Italy in 1799 by *Alessandro Volta* and an associate of his by the name of *Galvani.* For this reason electric current, especially that produced by batteries, is sometimes referred to as voltaic electricity, occasionally as galvanic electricity. Volta piled alternate discs of copper and zinc above each other, separating them with pieces of cloth moistened in a solution of common salt, and this produced electric current. This was the famous "volta pile." In reality it was the first "dry," or "moist" cell. None of the so-called dry cells are actually *dry* excepting a type which is made with a hollow perforated cylinder into which water can be poured when it is desired to use the cell. The latter are taken on exploring expeditions, etc.

42. A simple chemical cell is made by filling a glass jar with a solution composed of either salammoniac and water or sulphuric acid and water, and immersing into this solution two strips of different metals. The solution is known as the *electrolyte* and the pieces of metal as *electrodes.*

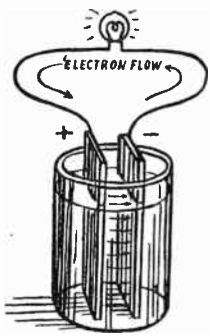


Fig. 19a. Simple Chemical Cell.

The following list includes substances used for electrodes for chemical cells. Reading from the top, each material will have a positive relation towards any material below it in the list. Generally the greater the difference between the materials the greater will be the efficiency of the cell.

List of electrode substances—

Carbon	Lead
Platinum	Nickel
Silver	Iron
Mercury	Cadmium
Copper	Zinc
Tin	

Many of the commercial cells of today employ electrodes of *carbon* and *zinc,* which, it will be noticed, are the farthest apart on the above list. The ordinary *dry cell* consists of a zinc cylinder filled with an absorbent material, such as sawdust or sand, containing the electrolyte, and the carbon electrode takes the form of a rod placed in the center of this. A

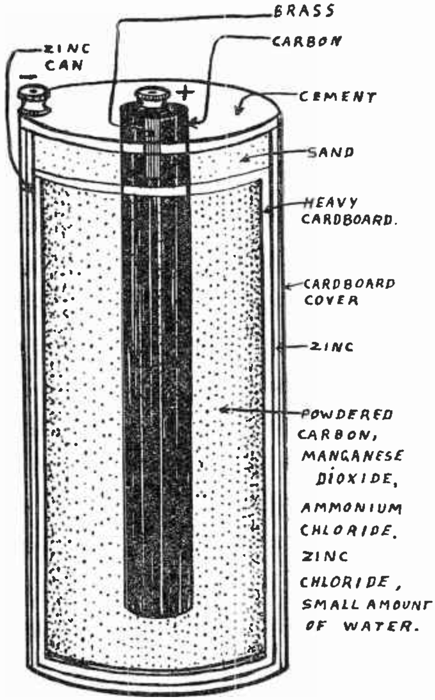


Fig. 19b. Cross-Sectional View of Ordinary Dry Cell.

common form of dry cell contains powdered carbon and manganese, combined with salammoniac and zinc chloride. There is a thick cardboard lining inside of the zinc can, to prevent a short-circuit between the zinc and the manganese, and also to act as an additional absorbent. When the zinc or other active element in a wet cell has been consumed, it is necessary to renew the active material and the electrolyte. The dry cell must be discarded entirely when it loses its efficiency. For this reason cells of this character are called *primary cells,* as compared with *secondary cells,* or storage batteries, which can be renewed many times by the simple process of sending an electric current through them in the opposite direction from their discharge.

43. The *chemical action* of the *primary cell* is as follows: for example, take a cell using a weak solution of sulphuric acid (H_2SO_4). For such cells a solution of about one part acid to twenty parts water, by volume, is used. If a strip of zinc is immersed in this electrolyte, it will be observed that bubbles immediately rise from the zinc. These bubbles are hydrogen, one of the gases of which water is composed, and which is released by the decomposition of the water as the acid attacks the zinc. The decomposition by chemical action is called *electrolysis.* The gas, if collected in a tube, can be ignited and will burn with a light blue flame. If a piece of copper be connected to the zinc electrode by means of a wire forming an external circuit, and immersed in the solution with the zinc, but not touching it, the bubbles will now rise from the copper. The bubbles rising from the copper are hydrogen, the same as those previously rising from the zinc. If the external circuit is broken, the action between the two electrodes ceases, although the acid will continue to attack the zinc. It appears that there is some action taking place between the two electrodes through the external circuit, as the action ceases upon the opening of that circuit. We find that the strain or pressure set up by the chemical action of the acid in consuming the zinc and releasing hydrogen gas causes a *difference of potential,* or difference in pressure, all along the wire composing the external circuit. If we examine this wire with a compass, we discover that the needle is deflected at right angles to the wire, according to the right-hand rule for magnetic lines of force around a charged wire. In other words, that the wire possesses properties of *magnetism.* The internal action

of the cell is sometimes explained as a movement of *ions.* As the acid attacks the zinc, it draws atoms of zinc into the electrolyte, gradually consuming and dissolving the zinc electrode. When the zinc is dissolved by the acid, the atoms which pass into the solution carry a positive charge, leaving a corresponding negative charge on the portion of the zinc electrode still remaining. As the positively charged zinc *ions* accumulate in the electrolyte, they give a positive charge, and the hydrogen *ions* are repelled from the zinc to the copper plate, where they produce a positive charge on the copper, and then pass off as bubbles. And this action produces *electro motive force,* or voltage, frequently abbreviated to E. M. F.

The action of salammoniac on zinc and carbon has the same effect. The salammoniac attacks the zinc, producing an accumulation of negative electrons on that electrode and driving hydrogen bubbles against the carbon, making that electrode positive. Then, when the external circuit is closed, the positive attraction of the carbon electrode draws the electrons around the circuit from the negative zinc.

44. Several different types of chemical cells have been invented, principally for the purpose of overcoming the effects of the hydrogen gas, or bubbles, moving back toward the zinc electrode, which causes the cell to "run down," or "polarize." The best known of these different cells are the Leclanche, Daniell, and the bichromate cell. In the simple chemical cell described in the preceding paragraphs, no attempt is made to prevent polarization. In the bichromate cell bichromate of soda, or of potassium, is used in connection with the acid. The bichromate has a strong affinity for hydrogen, and by chemically arresting this gas, prevents it from returning to the zinc plate, and reversing the polarity of the cell. The *Daniell cell,* commonly known as the gravity, or crowfoot cell, on account of the bird's-claw shape of its plates, is used extensively by land-wire telegraph companies for operating telegraph sounders. It is composed of zinc and copper electrodes, with dilute sulphuric acid surrounding the zinc electrode, and forming zinc sulphate, with sulphate of copper (bluestone) dissolved in water surrounding the copper electrode. These cells depend on the force of gravity to keep the chemicals in proper relation. The hydrogen does not rise in bubbles as in the simpler form of the chemical cell. Instead, it unites with the sulphuric acid and pre-

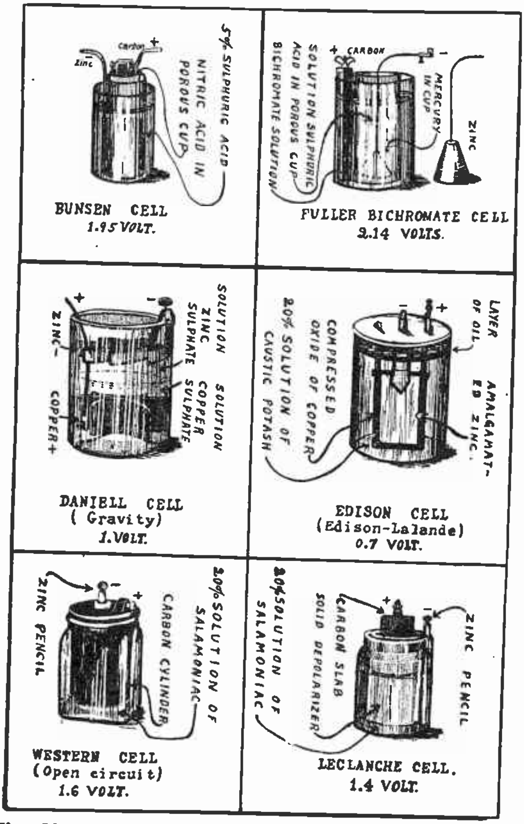


Fig. 20. Various Commercial Types of Chemical Cells.

cipitates pure copper crystals on the copper electrode, leaving pure sulphuric acid. The pure sulphuric acid then proceeds to dissolve the copper crystals, and the electrolyte is automatically kept in a saturated condition. This action prevents polarization. In the *Leclanche cell,* the solution is ammonium chloride, commonly called salammoniac, one part salammoniac to four parts of water. The electrodes are carbon and zinc, and the depolarizer a solid one. In dry cells, a depolarizing substance is sometimes placed inside of a cloth bag, around the carbon electrode, and the electrolyte is in the form of a jelly. Cells used for door-bell ringing, etc., where they stand in an open circuit most of the time, do not require a depolarizer. These are sometimes referred to as *"open-circuit cells."*

As pure zinc is difficult to obtain, foreign particles, principally iron, imbedded in it, often cause a *local chemical action* between the zinc and the foreign particle. This reduces the efficiency of the cell. It may be overcome by dipping the piece of zinc into sulphuric acid and then rubbing it with mercury. This treatment is known as *amalgamating* the zinc. As the zinc is inexpensive, however, this is not worth while except as an experiment, and it is customary to replace a bad zinc electrode with a new one.

45. The various types of cells manufactured have each their characteristic voltage, which is the result of the particular combination of minerals and chemicals used in their composition. *The same combination of materials will always cause the same pressure.* The *capacity* of the cell to deliver current at this pressure, or the amount of current which the cell may be expected to give, *depends upon the size of the plates and their distance apart.* The current is increased by placing the electrodes close together, and decreased by drawing them farther apart.

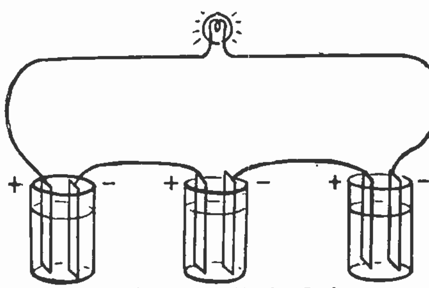


Fig. 21. Cells in Series.

46. A number of cells may be used in a row, with alternate positive and negative plates connected. This is called a *series* connection, and the *pressure* is equal to the pressure of one cell multiplied by the number of cells in the row. The *quantity of current* is not increased. When on the other hand, all the positive plates are connected to one side of the circuit, and all the negative plates to the other, the *quantity* of current is increased to an amount equal to the quantity procured from one cell, multiplied by the number of cells. This is called a *parallel connection.* It does not

increase the pressure, only the quantity. The quantity of current in the circuit is measured in units called amperes, and the pressure in volts. (See paragraph 55 for definitions.

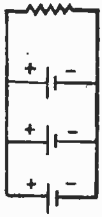


Fig. 22. Cells in Parallel.

A parallel group connected in series is generally called a series-parallel connection; and the pressure and amount of current obtained can be determined by the above rules, applied to each group, and then to the connections of the groups in the circuit. Various combinations are made in this way, for obtaining an increase in quantity or pressure or both, and are termed multiple connections.

47. When one end of the wire is disconnected from the cell, no current flows in the external circuit. This wire provides a *path from one terminal back to the other.* It may not be exactly a circle; but it is *circuitous,* returning to its starting point. The same rule applies to the larger and more complicated connections. There must always be a path provided for the current to get around back to its starting point in some manner. Hence, the word *circuit.* When the fundamental idea of a simple electric circuit is grasped, and kept in mind, it is easy to understand many of the familiar electrical devices which we see in common use, and to trace out the more complicated combinations of circuits of elaborate apparatus. A *closed circuit* is one which is completely closed, so that the current can flow through it without interruption. An *open circuit* is one which is opened at some point in the path of the current. In effect, when the path is opened it ceases to be a circuit. The action of closing and opening the circuit of the transmitting apparatus by means of the key, is the secret of the dots and dashes of the telegraphic

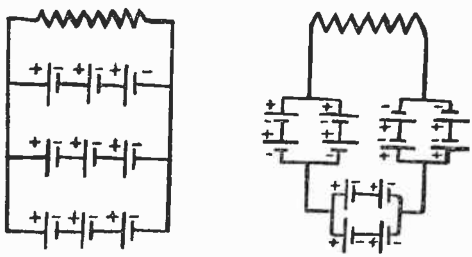


Fig. 23. Multiple Connections of Cells.

code. Chemical cells which are designed for door bells, and operating buzzers, where they stand on open circuit most of the time, are called *open-circuit cells.* They do not require a depolarizer, as they are used for such a short time that the polarization can not take place. Cells containing depolarizers, and designed for continuous work on closed circuit, are called *closed-circuit cells.*

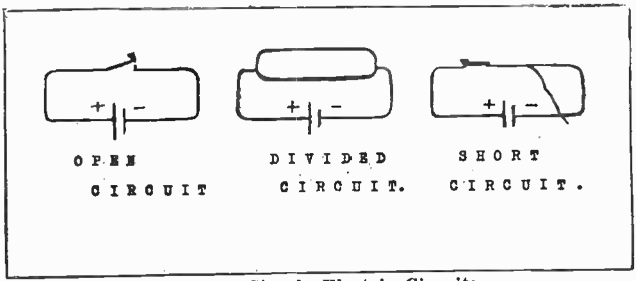


Fig. 24. Simple Electric Circuits.

A *divided circuit,* as its name implies, is a divided path for the current; and a *short-circuit* is a shortened path, generally accidental.

A student's practice buzzer set, and two different door-bell circuits, are illustrated here as examples of the practical application of the simplest circuits. The grounded door-bell circuit has the advantage of a saving in wire, as only one wire is required, and the ground serves as a conductor for the return of current to the cell.

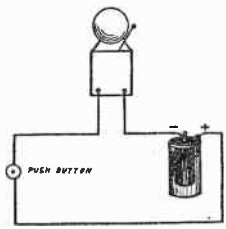


Fig. 25. Simple Door-Bell Circuit, Using Wet or Dry Cell.

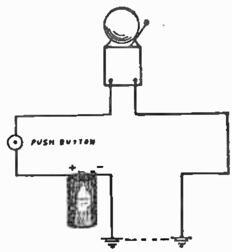


Fig. 26. Grounded Door-Bell Circuit.

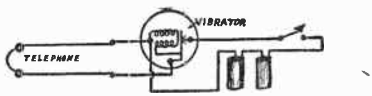


Fig. 27. Circuit for Student's Buzzer Practice Set.

48. As anyone engaged in the use and installation of radio apparatus frequently finds it necessary to make electrical connections to the power and lighting systems of ships or buildings, they should have a general knowledge of electrical work, aside from that which is strictly radio. It is a poor sort of a radio electrician who is mystified by an ordinary house circuit, which is much simpler than any apparatus used in radio. The circuits of a three-wire system for house wiring, direct current, are shown here. The three-wire system is now in general use for this purpose. It has the obvious advantage of providing two different powers as desired. This is accomplished by the use of two 110-volt dynamos at the power station, and a neutral wire between them, as shown in figure 28; or by the use of a three-wire generator. By tapping across one side of the circuit, or the circuit of one dynamo only, 110 volts will be obtained, but by tapping across both of them and eliminating the neutral wire, 220 volts are secured for power for motors, etc. (The action of the three-wire system is further explained in paragraph 127.) Lights are generally connected in parallel, as shown in the examples of house wiring; but occasionally they may be seen connected in series. An interesting example of this is the trolley-car lights, where the full voltage of a 550-volt line is sent through five 110-volt lamps, this being possible on account of the series resistance of the five lamps. (See chapter 6.)

49. In making connections to city power lines, one must be careful to see that no short-circuits are formed, which will immediately blow the fuses. Also, all wires must be well insulated. Where it is necessary to splice the wire, it should be scraped clean, twisted tightly in such a manner that it can not be pulled apart, and then neatly covered with friction-tape. The city fire underwriters' rules must be kept

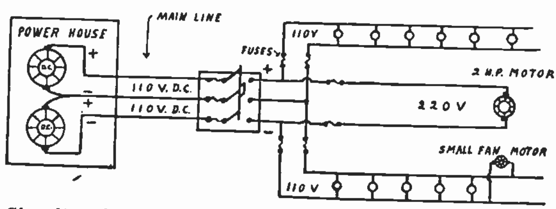


Fig. 28. Circuits of Ordinary D. C. Three-Wire System of House Wiring.

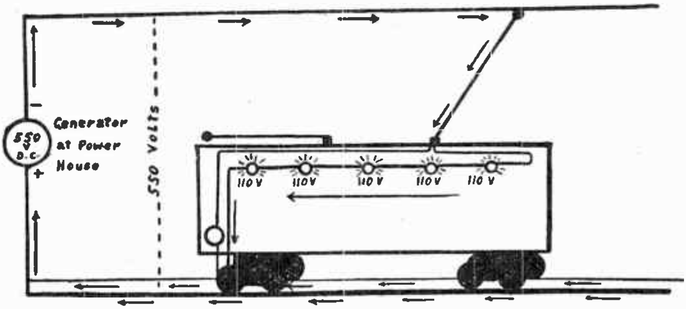


Fig. 29. Circuits for Trolley-Car Lights on 550-Volt Line, Each Lamp 110 volts.

in mind, and, if desiring to make extensive installations, it is well to investigate the rules in each particular case, so as to avoid waste of time and material. (Copies of the National Electric Code may be obtained free from the National Fire Underwriters, 16 Williams Street, New York. Information concerning local applications of the code can be secured from the local fire inspection bureau.)

CHAPTER 6

Units of Electrical Measurement

Resistance and Permeability—Definitions of Ohm, Ampere, Volt, etc.—Ohm's Law—Effects of Connecting Resistances in Series and Parallel—Coulomb—Power Units—Circular Mil—Table of Constants of Wires—B. & S. Copper Wire Tables—Line Drop—Direct-Current Problems

50. All electric circuits have naturally a certain amount of resistance. *Resistance* may be defined as the *opposition* offered by a substance to the flow of an electric current. The amount of this opposition in the circuit is due to the size and *permeability* of the conductors. The resistance is invariably the reciprocal of the conductivity, or *conductance*. Resistance is measured in units called *Ohms*. Occasionally one sees the unit of conductance called the *mho,* as representing the opposite of the ohm. Sometimes sections, or coils, of wire having a higher resistance than the rest of the circuit, are connected in such a way that practical use is made of their opposition, and some desired effect obtained in the way of control of the amount of current allowed to pass a given point in a given time. When a resistance device of this kind is placed in series in a circuit, the current is forced to try to pass through it, that which does not pass through being *dissipated* in the heat produced by the friction between the moving electrons and the obstructing ma-

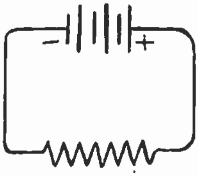


Fig. 30. A Single Resistance Coil in Series with a Battery of Cells.

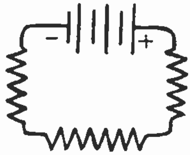


Fig. 31. Three Resistance Coils in Series.

terial of the conductor. When two or more resistances are placed in series their ohmic resistance is exactly in proportion to their number and size, and the total is obtained by *adding the ohmic resistance of the individual coils.*

51. On the other hand, if two or more resistances are placed in shunt, or parallel, in a circuit, their total resistance is not increased in proportion, on account of the current dividing between them. If one can imagine the circuit

for the time being as consisting of hollow water pipes through which water is flowing, instead of wire conductors of electric current, it is easy to understand this. Take, for example, three resistances in series. If they were three tight places in a water pipe, the water would be forced to pass

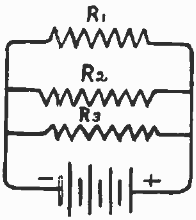


Fig. 32. Resistance in Parallel.

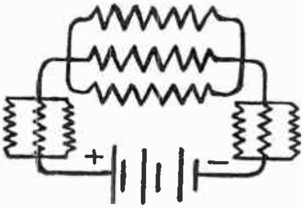


Fig. 33. Resistances in Series-Parallel Groups.

through them each *consecutively,* whereas if the three tight places were composed of small pipes connected across the water line, the water would divide, and a portion of it pass through each small pipe simultaneously. *Each small pipe* would pass a *portion* of the *total quantity* of water, in *proportion* to its size and frictional resistance.

52. The following simple formulæ are standardized methods for measuring the total resistance of resistances connected in various ways in electric circuits. Three *like resistances,* say of 3 ohms each, connected in *series,* will add to that circuit a resistance of 9 ohms. If three *unlike resistances,* say of 2, 3 and 4 ohms, are connected in *series,* the resistance added to the circuit will still be 9 ohms. When, however, the three resistances are connected in *parallel,* as in figure 32, the result is entirely different. *If the parallel resistances are alike, the resistance added to the circuit is equal to the ohmic resistance of one coil divided by the number of coils, or*

$R_1 = 3$ ohms
$R_2 = 3$ ohms
$R_3 = 3$ ohms.

Then, the total resistance of the coils, R_1 and R_2 and R_3, in parallel, is equal to 3 divided by 3, or 1 ohm.

$$R_1 + R_2 + R_3 = \frac{3}{3} = 1.$$

Where UNEQUAL *resistances are connected in parallel, the division of current will be in proportion to the conductance of the branches, or in inverse proportion to their resistance. The higher the resistance, the lower the conductance, and vice versa. The lowest resistance in the group will draw an amount of current which will be proportionately greater than that drawn by the higher resistance in the same circuit.* With the three resistance coils referred to above, having respectively an ohmic resistance of 2, 3 and 4 ohms, the joint resistance of the three coils in parallel in the circuit is found by first calculating the conductance.

$R_1 = 2$ ohms
$R_2 = 3$ ohms
$R_3 = 4$ ohms.

Then, the conductance of R_1 is the reciprocal of its resistance, or $\frac{1}{2}$. The conductance of R_2 is $\frac{1}{3}$, and the conductance of R_3 is $\frac{1}{4}$.

We find that the common denominator is 12, so,

$$\frac{1}{2} + \frac{1}{3} + \frac{1}{4} = \frac{6}{12} + \frac{4}{12} + \frac{3}{12} = \frac{13}{12} \text{ mhos.}$$

$\frac{13}{12}$ mhos $= \dfrac{1}{\frac{13}{12}}$ ohms $= \frac{12}{13}$ *ohms,* or .92 ohm, which is the *joint resistance* of the three coils in the circuit in parallel; and the division of current between the three coils will be as follows: R_1 will take 6/13 of the current, R_2 4/13, and R_3 3/13.

A simpler method of determining the joint resistance of parallel resistances, when there are not more than two in the group, is to multiply the number of ohms of resistance in each coil, and divide this product by the sum of the resistances. For instance, if a coil of 10 ohms resistance is connected in parallel with a coil having 5 ohms resistance, the joint resistance of the two coils will be $3\frac{1}{3}$ ohms, which was found by dividing 50 by 15.

$$\frac{5 \times 10}{5 + 10} = 3\frac{1}{3}$$

53. The ohmic *resistance,* combined with the *pressure* back of the current, determines the *amount of current* which can pass through a given circuit. With any given pressure remaining constant, the current is varied in inverse ratio to any change in resistance. Hence, the resistance, the pressure or voltage, and the current in amperes, are inseparably associated factors. They are measured in units which have been *internationally* agreed upon. The *ohm,* after a German who discovered the law now known as Ohm's law; the *volt* after the Italian, Alessandro Volta, who invented the voltaic cell; and the *ampere* after a Frenchman named Ampere. Also, we have the *coulomb,* named after Dr. Coulomb, who discovered the law which was named after him; and the *watt,* or unit of power, after Isaac Watts, whose name is associated with the power of steam.

54. The *ampere* may be measured by use of the unit representing *the amount of silver deposited on metal in an electroplating bath.* Electroplating is based on *electrolysis.* For instance, as a simple experiment, dissolve one ounce of zinc sulphate in a tumbler of water, and insert two copper electrodes, which are connected by means of wire to a battery of four or five cells. In half an hour or so, the copper electrode on the negative side of the charging current will show distinct signs of discoloration. It is being *plated* with the zinc, which is released from the zinc sulphate by electrolysis due to the current passing through it, and carried through the solution to the negative electrode by the chemical action of the cell. If left long enough, all of the zinc will be deposited on the copper and only the sulphuric acid will be left in the solution. Incidentally, this makes a crude form of *"storage cell."* If, after disconnecting the battery used for the charging process, the terminals of the electroplating cell are connected in series with a galvanometer, a flow of current will be indicated; and soon the zinc will be eaten from the zinc-plated electrode exactly as the zinc electrode is consumed in the simple chemical cell.

Instead of zinc and sulphuric acid, any one of a number of combinations may be used and practically any desired kind of plating accomplished. It is necessary in some cases to copper plate some metals before they will take gold or silver plating. In the process of silver plating the material to be silver plated is placed at the negative pole of the tank. The silver-plating bath may consist of a block of pure silver immersed in a solution of cyanide of potassium, or it may consist of a solution of nitrate of silver. The metal is connected as the positive pole of the tank, and the action of the solution gradually deposits a plating of the metal on the object placed at the negative pole.

55. Definitions:

AN AMPERE is the current which is maintained by a pressure of one volt through a resistance of one ohm (or, that current which will cause a solution of nitrate of silver to deposit metallic silver at the rate of .001118 gram per second).

AN OHM is the resistance which will permit one ampere of current to pass a given point in a circuit when the pressure is one volt. (The International standard is represented by the resistance of a column of mercury 106.3 centimeters high and weighing 14.5421 grams at 0° Centigrade.)

A VOLT is that pressure which will maintain a current of one ampere through a resistance of one ohm.

A COULOMB is the quantity of current passing a given point in a circuit when there is one ampere flowing for one second.

One milliampere = one thousandth of an ampere.
One microampere = one millionth of an ampere.
One megohm = one million ohms.
One microhm = one millionth of an ohm.
One millivolt = one thousandth of a volt.

56. To find the quantity of electricity in coulombs passing through a circuit in a given time, multiply the current strength in amperes by the time, in seconds, or

$$Q = I \times T.$$

In the early days of electricity, what we now think of as *current* was regarded as *intensity*, hence the letter I is now used in all formulae as the symbol for *current*. To find the current strength, divide the quantity of electricity in coulombs by the time in seconds, or

$$I = \frac{Q}{T}.$$

To find the time in seconds for a given quantity of electricity to pass a given point in a circuit, divide the quantity in coulombs by the current strength in amperes, or

$$T = \frac{Q}{I}.$$

Quoting from Swoope's lessons in Practical Electricity, "Distinction must be made between the total quantity of electricity that passes through a circuit in a given time and the rate of flow of electricity during that time. For example, at the rate of flow of one gallon per second, 3,600 gallons of water would be delivered to a tank in an hour, the total quantity being readily distinguished from the rate of flow. We might take the *gallon per second* as a unit of rate of flow and name it, but this has not been done in hydraulics, although it is done in the case of electricity. The total quantity of water equals the rate multiplied by the time in seconds: thus, at a rate of flow of 8 gallons per second, in 60 seconds the total quantity delivered would be 480 gallons, which same quantity could be delivered to a tank in one second if the rate were 480 gallons per second, or in one-half second if the rate were 960 gallons per second, or in 480 seconds if the rate were only one gallon per second. If a current of one ampere flows for 60 seconds, then the total quantity is 60 ampere-seconds, or 60 coulombs."

Coulombs are comparable to total quantity in gallons and amperes to gallons per second. In other words, the *coulcomb* is the unit of *quantity* and the *ampere* the unit of *rate of flow.*

57. *Ohm's law* deals with the inseparable association of the voltage, the current and the resistance, referred to in paragraph 53. E is used as the symbol of voltage, or electro-motive force. R as the symbol for resistance, and I to represent amperes. Then, where the voltage and the re-

sistance are known, and we desire to determine the amount of current flowing, it can be found by the following formula:

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

Likewise, resistance is equal to voltage divided by amperes, or

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

and electromotive force is equal to amperes multiplied by resistance:

$$E = I \times R$$

58. In practical applications of the laws of physics, units of *work* and of *force* are constantly employed. *Force* might be defined as the *exertion used in accomplishing work;* and *work* as the *motion,* or *transfer of energy accomplished by force.* Energy is never actually created. Energy already at our disposal is merely transferred or transformed from one state or position to another, where it will serve our purposes better. This is known as the law of *conservation of energy.* If, during the process of transfer of energy, heat is created where heat is not the object, this energy which is transferred into heat is *wasted,* so far as its application to our purpose is concerned. However, that *energy is not lost.* It is merely converted into *heat* instead of into *motion* or *electrical* or *mechanical lifting* or *pulling power,* or whatever other form of energy we wish to use. Work accomplished equals the amount of force exerted multiplied by the distance through which it is exerted, both in overcoming intervening resistance and in successful transfer of energy.

Thus, *Work* = force × distance.

Power adds the element of time to work, and may be defined as the *rate at which work is done.* It can be seen that if a given amount of work is accomplished in one hour, at a given power, accomplishment of the work in one-half hour requires a greater power than that used for doing the work in one hour.

$$Power = \frac{\text{work}}{\text{time}}.$$

59. The unit of *mechanical power* is the *foot-pound, which is the force which will lift one pound against the force of gravity for a distance of one foot.*

> *33,000 foot-pounds per minute is the unit of mechanical horsepower.*

As the units of electrical measurement are based on the *second* of time, rather than on the minute, for making transfers of energy from mechanical to electrical power, or *vice versa,* we divide the time into seconds.

> *550 foot-pounds per second is also one mechanical horsepower.*

Electrical power is measured in *watts.*

> *A watt is the power produced by a current of one ampere under a pressure of one volt through a resistance of one ohm.*

$$\text{Power} = E \times I.$$

$$I = \frac{P}{E}$$

$$E = \frac{P}{I}$$

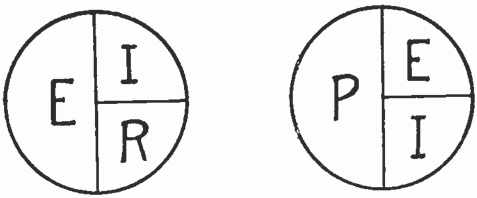


Fig. 34. Circular Presentation of Ohm's Law, and the Law for Power. (These are convenient in working practical problems. The unit occupying the half circle is always equal to the product of the units occupying the two quarters; and either unit occupying a quarter circle equal to the result of dividing the half circle unit by the unit in the other quarter).

The *total work* is the product of the *power expended and the time:* and the unit of electrical work, or energy, is the *joule.*

*A joule is the energy expended when one ampere flows through a resistance of one ohm for one second.**

$$Joules = E \times I \times \text{time in seconds.}$$

$$Watts = \frac{\text{joules}}{\text{time in seconds}}$$

60. Dr. James Joule, of England, established, in about 1845, what has since been known as *Joule's equivalent,* or *Joule's law.* He proved that a paddle-wheel revolved in a vessel containing one pound of water, by means of a falling weight fastened to a cord which was wound around the axle of a wheel, would raise the temperature of the water one degree Fahrenheit, when the energy exerted by the mechanical device was exactly 778 foot-pounds. Also that if the water was heated by a current of electricity, until its temperature was raised one degree, the electrical energy employed must be the equivalent of 778 foot-pounds of mechanical energy, which was about 1055 watts. From this it was deduced that one foot-pound is equal to 1.356 watts, and that one watt is equal to 0.7375 foot-pound per second. Hence,

$$\frac{550}{0.7375} = 746 \text{ watts} = 1 \text{ electrical horsepower.}$$

(Since the horse has been largely replaced by machinery in the mechanical world, there has arisen a sentiment in favor of rating all electrical power machinery, turbines, etc., in kilowatts, abolishing the horsepower unit of power. If this is done, it will, of course, take several years for the complete adjustment to be made.)

When the resistance of an electric circuit is known, the total energy expended in joules may be found by squaring the current and using the following formula.

$$\text{Joules} = I^2 \times R \times \text{time in seconds.}$$

*1 joule = 10,000,000 ergs.
1 erg = work done in moving a body one centimeter by a force of one dyne.
1 dyne = force which, acting on a mass of one gram, will accelerate its velocity by one centimeter per second.

Joules equal energy consumed, including that used in generating heat. It has been found that one joule is the same amount of energy for doing work as .7375 foot-pound, which is 1/746 of a mechanical horsepower per second.

Watts, where used in large amounts of power, are for convenience measured in units of one thousand.

One thousand watts = one *kilowatt.*

Rate at which watts are expended: $P = E \times I$.

Watts lost, when E is known: $P = E \times I$.

Watts lost, when E is not known, but when current and resistance are known: $P = I^2 \times R$.

Then, watts lost: $P = \frac{E^2}{R}$, $R = \frac{P}{I^2}$, and $I = \sqrt{\frac{P}{R}}$

61. The *hour* is frequently used in measuring electric power or current for various purposes. For instance, we have the *watt-hour, which is one watt of power expended for one hour.* (This is the same as 3600 watt-seconds, or 3600 joules.) A *kilowatt-hour is one kilowatt of power expended for one hour.* Watt-hours and kilowatt-hours are used in reckoning charges for city light and power bills, and the meters used for this purpose give readings in these units. *An ampere-hour is one ampere flowing for one hour,* or at the rate of one ampere for one hour (3600 coulombs). Ampere-hour meters are generally installed to indicate the amount of current used in charging storage batteries.

62. In practical electrical work we find continuous use for the above rules, especially for Ohm's law. For instance, considering the chemical cell and its manner of connection in a circuit. In figure 19a, paragraph 42, we have a simple chemical cell, and a loop of wire representing an external circuit, in which we have placed a lamp to prevent short-circuiting the cell. The amount of current flowing is determined by the principle represented by Ohm's law. We have three resistances in series, viz. the ohmic resistance of the lamp plus that of the wire forming the loop, and the internal resistance between the two plates of the cell. We employ

a large R as the symbol for the external resistances and a small r as the symbol for the internal resistance.

$$R + R + r = \text{total resistance of the circuit.}$$

Ohm's law is applicable to each resistance separately. The E. M. F., or voltage, of any particular type of cell depends upon the amount of electrical energy caused by the difference of potential between the two electrodes, as the chemical energy operates in decomposing the water, consuming the active electrode, and liberating hydrogen gas. This varies in different makes of cells, on account of the different materials used; but each type of cell, when in efficient condition, will always give about the same voltage. Increasing or decreasing the size of the electrodes, or moving them closer together or farther apart, makes no difference in the E. M. F. However, as $I = \frac{E}{R}$, the size and distance apart of the electrodes does affect the quantity of current which can be procured from the cell. The larger the plates, and the closer they are, providing they are not so close as to short-circuit, the lower will be the internal resistance of the cell, and therefore the greater will be the quantity of current which the cell will give to an external circuit. The internal resistance depends upon the kind of electrolyte used, and the thickness and surface area of the plates and their distance apart.

r = internal resistance of a cell.

K = ohmic resistance of one mil-foot of the particular metal used. (One foot long and one-thousandth of an inch in diameter.)

r of any cell $= \frac{\text{distance between plates}}{\text{submerged surface area of plates}}$ multiplied by K.

63. In figure 21, paragraph 46, we have three cells in series. The pressure is three times that of one cell. Also the resistance is three times that of one cell; and the amount of current flowing will be in proportion to the total opposition offered by the three resistances in series.

Example

Three 1.25-volt dry cells, each giving 10 amperes of current on short-circuit, are connected in series in a flash-light.

(a) What is the internal resistance of one cell?

$$R = \frac{E}{I} = \frac{1.25}{10} = .125 \text{ ohm}$$

(b) What is the total resistance of the three cells?

$.125 \times 3 = .375$ ohm

(c) What current is obtained from the three cells in series?

$$I = \frac{E}{R} = \frac{3.75}{.375} = 10 \text{ amperes}$$

64. In figure 22, paragraph 46, we have the same three cells as above, connected in parallel. Cells connected in this manner, with all of the positive electrodes joined together, and all of the negative electrodes joined together, create a condition almost identical with one large cell having plates of the size represented by the total area of all of the separate plates. The pressure is equal to that of only one of the cells. The internal resistance obeys the law for resistances in parallel, as in figure 32, and is therefore less than the resistance of one cell. And as $I = \frac{E}{R}$, and the internal resistance is less than that of one cell, the current obtained is about three times that obtained from one cell.

The same three cells referred to in the preceding paragraph are connected in parallel.

(a) What is the total resistance of the group of cells?

$$R = \frac{.125}{3} = .041 \text{ ohm}$$

(b) What current can be drawn from the cells?

$$I = \frac{E}{R} = \frac{1.25}{.041} = 30 \text{ amperes}$$

65. The resistance of various sizes and kinds of wire in electric circuits is always an important consideration. A wire of a certain degree of permeability will allow direct current to pass through it at a certain voltage in direct ratio to its size.

The larger the size of the wire the less the resistance of it, and the larger the amount of current which it will allow to flow through it at a given pressure. After determining the size of the wire, and its degree of permeability, or its resistance per mil-foot as compared to one mil-foot of standard Brown and Sharpe annealed copper wire, the problems arising in the use of various types of wire are workable by Ohm's law.

Variable resistance coils, usually called *rheostats,* are used extensively for controlling the current in all types of electrical and radio apparatus.

66. Measurement of wires to determine their sizes are made in either circular or square mils.

> *A circular mil is a circle one-thousandth of an inch in diameter (.001 inch).*

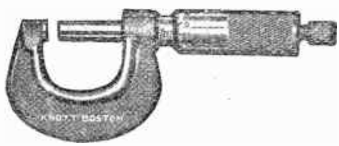


Fig. 35. Micrometer.

These units are not referred to as thousandths, but as individual units. A wire having a diameter of .003965 of an inch is said to have a diameter of 3.965 mils. There are several tables, but the Brown and Sharpe annealed copper wire table is generally considered the standard in the United States. It is sometimes referred to as the American Wire Gauge. To determine the size of a wire, measure its diameter in mils with a micrometer, and refer to the wire table, where you will find its size number, its cross-sectional circular mil area, pounds per thousand feet, etc.

The micrometer (see figure 35) consists of a clamp and a measuring device of exceedingly accurate adjustments. The wire to be measured is inserted into the clamp. The small scored thumb screw at the end of the handle, sometimes

Fig. 36. Handy Pocket Wire Gauge.

called a vernier, is used to tighten the rod to just the right grip without flattening the wire. The portion of the scale which shows in the cut is a part of a scale exactly one inch in length. It is marked off in *tenths* of an inch, which of course are each one hundred mils long. The separate mils are not marked, but the tenths are divided into quarters, each of these being 25 mils long. The portion of the handle bearing the numbers arranged vertically is revolved as the wire is inserted in the clamp. It makes one complete revolution for precisely twenty-five mils on the scale, and the vertical marks on the revolving portion show the actual mils distance that the clamp has been moved. We find that five of the twenty-five mil divisions on the scale, or 125 mils is equal to one-eighth of an inch. *To reduce a fraction of an inch to number of mils, divide 1,000 by the denominator and multiply the result by the numerator.* Figure 36 represents a pocket gauge, which offers a much more convenient method of determining the size of a wire, and it will suffice for all practical purposes where it is not necessary to measure the mils diameter especially. Such gauges are also made giving readings of circular mils diameter instead of the size of the wire. Figure 36 is actual size, and shows the actual sizes of the wires of different standard numbers. The slit through which the wire slips, and not the round hole, is the size of the wire.

67. The circular mil cross-sectional area of a wire is found by squaring its circular mil diameter, *the units being circles.*

Area in C. M. = d^2, and diameter = $\sqrt{\text{C. M.}}$

It is frequently necessary to know the C. M. area of a wire in order to compute its resistance, by use of the value of K of that material, K being the resistance for *one* circular mil one foot long and known as the *constant* of that particular conductor.

Table of Values of K (resistance per mil-foot) of various Metals at a Temperature of 68 degrees Fahrenheit.

Silver	9.84	Iron	63.35
Copper	10.79	German silver	128.29
Aluminum	17.21	Platinoid	188.93
Zinc	36.69	Mercury	586.24
Platinum	59.02	Nichrome	660.00

To find the *resistance* of a wire when its length and C. M. area are known,

$$R = \frac{L \times K}{C.M.}$$

To find the *length* when the resistance and C. M. area are known,

$$\text{Length} = \frac{R \times C.M.}{K}$$

To find the C. M. area when the length and resistance are known,

$$C.\ M. = \frac{\text{Length} \times K}{R}$$

In measuring a stranded wire, composed of non-insulated conductors, the corresponding size in a solid round wire would be approximately the size which would have a circular mil diameter equal to the square root of the product of the circular mil cross-sectional area of oue of the strands and the number of strands. For instance, take a wire composed of 15 strands of bare copper. You measure one of the strands with a micrometer and learn that it is number 30 wire. This has a circular mil cross-sectional area of 100.1 circular mils. Then the circular mil area of the ends of the fifteen strands must be a trifle over 1500 circular mils. The square root of 1500 is about 39; and the nearest to this diameter is number 18 wire. Therefore, the conductor composed of 15 strands of number 30 bare wire is about the equivalent of a number 18 solid wire.

68. The resistance of all materials used in electrical work varies with *temperature*. All pure metals and most alloys show an increase in resistance as the temperature rises. Carbon and electrolytes decrease in resistance with a rise in temperature. For instance, if you have two lamps, one with a tungsten filament and the other with a carbon filament, you will find that the resistance of the tungsten filament increases with the heating of the filament, and that the resistance of the carbon filament decreases with heat. 10.8; the resistance of No. 10 Brown and Sharpe annealed copper wire at a temperature of about 75 degrees Fahrenheit, is generally used for the value of K for ordinary commercial copper wiring; and 1,000 feet of No. 10 B. & S. annealed copper wire is the usual commercial wire standard for one ohm of resistance.

Increasing the diameter of a round copper wire one circular mil will increase its current-carrying capacity one ampere.

Some conductors are square or rectangular, and these must be measured in square mils. *A square mil is a square measuring one-thousandth of an inch each way.* (It is one-millionth of a square inch.) It will be seen that the square mil is somewhat larger than the circular mil. In order to take advantage of the tables which have been compiled for K, etc., of circular mil-feet, it is necessary to convert square mils to the area which would be its equivalent in circles.

To determine the square mil area of a conductor multiply its dimensions on each side, in mils.

To convert the area in square mils to the equivalent area in circular mils, multiply by 1.2732.

When it is desired to convert circular mil area to the equivalent area in square mils, multiply by .7854.

69. Volts and amperes are measured by voltmeters and ammeters. With a few exceptions, these are operated by an application of the laws of magnetism to a moving coil of wire. The *voltmeter* is made of many turns of fine wire, with a high-resistance coil in series with this coil. It is connected in shunt, or parallel, across the circuit. Voltmeters thus register the *pressure* of the current in the circuit, without allowing the full amount of current to pass through them, much as mechanical pressure gauges are used to indicate the pressure of steam or gas without passing the full amount of either. *Ammeters,* being constructed for measuring the *quantity* of electricity flowing in the circuits in which they are placed, are necessarily made of much heavier wire, and are connected directly in series in the circuit. (Meters are taken up in detail in chapter 38.

70. If we explore a circuit having devices of differing resistance connected in it, we will find that the pressure is not the same throughout the circuit; but varies at spots in this circuit, in proportion to the local resistance of the wires, etc., connected in it. Also, we find that there is energy lost along a wire, or "line," composing a circuit. The longer the wire, of a given circular mil area, and the same K, the greater will be this *loss* or *drop in voltage*. An illustration of this principle is where a steam piston forces water from a tank into a pipe at a pressure of, say, 100 pounds per square inch. Suppose the pipe is 25 feet long, and at the end of it water is taken from the pipe for power purposes. The water will not come out of the pipe at a pressure of 100 pounds per square inch, on account of the energy which has been lost in overcoming the friction of the pipe, and its resistance due to its relative cross-sectional size. If the water comes out of this pipe at a pressure of 75 pounds per square inch, there has been energy dropped along the pipe at the rate of one pound per foot. We may be able to procure the same quantity of water from the pipe that we would if the pipe were shorter, but we can not procure it at the same pressure. Practically the same thing is true of electric circuits. Where the circuit is confined to short pieces of wire between its terminals, this factor is negligible; but when electrical work is performed in sending current over lines for some distance, this becomes a matter to be included in the engineering plans where installations are to be made. As heat is generated where energy is consumed in overcoming resist-

ance, the line drop becomes a subject for the fire underwriters. The maximum *line drop* allowable, under the fire underwriters' supervision, is usually about 10 volts per 1,000 feet of line. Of course it ordinarily would not be this much. If 110 volts is obtained from a power line supplied from a 120-volt generator, there has been a *line drop* of ten volts.

The power lost in heat is known as the "I square R" loss, or $I^2 \times R$.

Line drop in volts equals product of line resistance and line current.

Line resistance equals result of dividing volts dropped by line current.

Line current equals result of dividing volts dropped by line resistance.

Ohm's law may be applied to a portion of the circuit, or to the series resistance of the entire circuit. Suppose that we connect four 110-volt, 220-ohm, lamps in parallel across a power line supplied from a 120-volt d.c. generator, with the lamps lighted to full brilliancy. There is a line drop of ten volts. The parallel resistance of the four lamps composing the bank is one-fourth of 220, or 55 ohms. Applying Ohm's law to determine the current drawn by the lamps,

$$I = \frac{E}{R} = \frac{110}{55} = 2 \text{ amps.}$$

Proving the resistance of the lamp bank,

$$R = \frac{E}{I} = \frac{110}{2} = 55 \text{ ohms.}$$

Applying Ohm's law to the resistance of the line through which we have lost 10 volts,

$$R = \frac{E}{I} = \frac{10}{2} = 5 \text{ ohms.}$$

$$I = \frac{E}{R} = \frac{10}{5} = 2 \text{ amps.}$$

Now, suppose we consider the series resistance of the whole circuit.

$$55 + 5 = 60 \text{ ohms.}$$

$$\text{and, } I = \frac{E}{R} = \frac{120}{60} = 2 \text{ amps.}$$

If the resistance of the line is increased, approaching the value at which there would be a volt drop equal to the applied voltage, were the current constant, the *volt drop dwindles,* on account of the decreased current, so that it is practically impossible to obtain a volt drop to zero. For instance, in the same circuit, 60 ohms resistance in the line would cause a volt drop of 120 volts with 2 amperes flowing, *but* 2 amperes cannot flow under these conditions, so the volt drop is not equal to the voltage at the generator terminals. With the 60 ohms in series with the 55 ohms of the lamp bank, we have 115 ohms total resistance, and

$$I = \frac{E}{R} = \frac{120}{115} = 1.043 \text{ amps.}$$

Then the volt drop is $E = R \times I = 60 \times 1.043 = 62.58$ volts.

There is then a voltage of 120 — 62.58, or 57.42 volts at the lamps.

Instead of the 220 watts required for lighting the lamps, then, they are receiving only 57.42×1.043, or 59.89 watts.

Problems.

1. Three cells are connected in series, as in figure 21, paragraph 46. The internal resistance of each cell is .75 ohm. The pressure of each cell is 1.5 volt. The resistance of the external circuit is .75 ohm. What current flows?

Answer. 1.5 ampere.

2. In figure 25, paragraph 48, the resistance of the push-button is 1 ohm. The resistance of the door bell is .5 ohm. The internal resistance of the cell is .5 ohm. The E. M. F. of the cell is 2 volts. What current flows?

Answer. 1 ampere.

3. In figure 22, paragraph 46, three cells are connected in parallel to an external resistance. The internal resistance of each cell is 1.5 ohm. The external resistance is 1 ohm. The E. M. F. of one cell is 2 volts. What current flows?

Answer. 1.333 amperes.

4. A single cell has an internal resistance of .2 ohm, and gives a current of 10 amperes on short circuit. What is the E. M. F.?

Answer. 2 volts.

5. A single dry cell has an E. M. F. of 1.5 volts. An ammeter placed across its terminals indicates 20 amperes flowing. The ammeter and leads have a resistance of .045 ohm. What is the internal resistance of the cell?

Answer. .03 ohm.

6. Three resistance coils are connected in parallel, as in figure 32, paragraph 51. The E. M. F. of the battery of four cells is 8 volts. The resistance of R_1 is 2 ohms. The resistance of R_2 is 5 ohms, and the resistance of R_3 is 10 ohms.

(*a*) What is the total resistance of the three coils?

Answer. 1.25 ohms.

(*b*) How much current flows around the circuit?

Answer. 6.4 amperes.

(*c*) The total current flowing through the group of resistance coils is divided between them in proportion to their conductance. How much current flows through each separate coil?

Answer. I of coil $R_1 = 4.$ amperes;
I of coil $R_2 = 1.6$ amperes;
I of coil $R_3 = .8$ ampere.

7. How many ampere-hours will be recorded by a meter through which 120 amperes has passed for one-half hour?

Answer. 60 ampere hours.

8. How many coulombs have passed through a lamp in one-half hour with a current of 10 amperes?

Answer. 18,000 coulombs.

9. What potential must be applied to an incandescent lamp if it has a resistance of 220 ohms and requires .5 ampere?

Answer. 110 volts.

10. The current through the windings of a motor is 4 amperes and the pressure is 160 volts. What is the resistance?

Answer. 40 ohms.

11. Four 50-volt lamps are connected in series, and then connected in parallel across a 220-volt circuit. Each lamp in the series group has a resistance of 50 ohms. What additional resistance should be connected in series with the lamps to protect them from injury?

Answer. 20 ohms.

12. An incandescent lamp is rated at 55 watts and 110 volts. What is its resistance?

Answer. 220 ohms.

13. A trolley-car runs on 550 volts and has five 110-volt lamps in series, connected across the 550-volt circuit, as in figure 29, paragraph 48. The current flowing in the lamps is 2 amperes.

(*a*) What is the resistance of each lamp?

Answer. 55 ohms.

(*b*) What is the rating in watts of each lamp?

Answer. 220 watts.

(*c*) What is the resistance of the lamps in series?

Answer. 275 ohms.

14. If purchasing a generator, what K. W. should it be for a six-hundred-light installation, if standard 55-watt lamps are used?

Answer. 33 K. W.

15. What would be the K. W. rating of an electric motor required to be substituted for a 30-H. P. gasoline engine?

Answer. 22½ K. W. (22.38 K. W.)

16. How much current is flowing in the circuit represented by figure 28, paragraph 48, under the following conditions? There are six lamps in parallel across one 110-volt branch, and another bank of five lamps in parallel across the other 110-volt branch. Each lamp has a resistance of 240 ohms. The small fan motor also has a resistance of 240 ohms, and is connected in place of a lamp. A 2 H. P. motor is connected across the 220-volt line.

Answer. 12.28 amperes flowing.

17. Some 50-watt, 110-volt incandescent lamps are connected in a circuit supplied with current from a generator which has a difference of potential at its terminals of 160 volts. The lamps are in parallel. The resistance of the wire

carrying current from the generator to the lamps is 5 ohms, and there is a line drop to be taken into consideration. How many lamps are lighted in the circuit?

Answer. 22 lamps.

18. You wish to operate an electric toy from your 110-volt electric light socket. The toy is made to operate on 44 volts and has a resistance of 440 ohms. You decide to cut down the voltage of the line by using lamps in series. How many 55-watt, 110-volt lamps would you use in series to obtain the correct resistance?

Answer. 3.

19. An electricican wishes to replace a burned heating element in his soldering iron. It operates on 110 volts d. c. and must draw 8 amperes to produce the right amount of heat. He decides to use No. 24 Nichrome wire. How long shall he cut the wire?

Answer. 8.4 feet.

20. A UV-201-A vacuum tube used in a receiving set requires .25 amp. at 5 volts to light its filament to fullest brilliancy. A 6-volt storage battery is used for the filament power supply.

(*a*) What is the resistance of the filament?

Answer. 20 ohms.

(*b*) What rheostat resistance would be required in series between the filament and the battery to provide 5 volts at the filament terminals?

Answer. 4 ohms.

(*c*) How much resistance would permit two of the tubes connected in parallel to be lighted to fullest brilliancy?

Answer. 2 ohms.

(*d*) With a 30-ohm rheostat connected in series with the filament, what would be the current in the circuit?

Answer. .12 amp.

(*e*) What would be the volts dropped through the rheostat in question d?

Answer. 3.6 volts.

AMERICAN WIRE GAUGE (Brown and Sharpe)
(STANDARD ANNEALED COPPER WIRE AT 77 DEGREES FAHRENHEIT.)

Gauge No.	Diam. in Mils d	Area Cir. Mils d^2	Weight		Length		Resistance	
			Lbs. per 1000 feet	Lbs. per ohm	Feet per lb.	Feet per ohm	Ohms per 1000 feet	Ohms per lb.
0000	460.0	211660.	640.5	12810.	1.561	20010.	0.04998	0.00007805
000	409.6	167800.	507.9	8057.	1.968	15870.	.06303	.0001217
00	364.8	133100.	402.8	5067.	2.482	12580.	.07947	.0001935
0	324.9	105500.	319.5	3187.	3.130	9979.	.1002	.0003138
1	289.3	83690.	253.3	2004.	3.947	7913.	.1264	.0004990
2	257.6	66370.	200.9	1260.	4.977	6276.	.1594	.0007934
3	229.4	52640.	159.3	792.7	6.276	4977.	.2009	.001262
4	204.3	41740.	126.4	498.6	7.914	3947.	.2534	.002006
5	181.9	33100.	100.2	313.5	9.980	3130.	.3195	.003189
6	162.0	26250.	79.46	197.2	12.58	2482.	.4029	.005071
7	144.3	20820.	63.02	124.0	15.87	1968.	.5080	.008064
8	128.5	16510.	49.98	77.99	20.01	1561.	.6406	.01282
9	114.4	13090.	39.63	49.05	25.23	1238.	.8078	.02039
10	101.9	10380.	31.43	30.85	31.82	981.8	1.019	.03242
11	90.74	8234.	24.92	19.40	40.12	778.5	1.284	.05155
12	80.81	6530.	19.77	12.20	50.59	617.4	1.620	.08196
13	71.96	5178.	15.68	7.673	63.80	489.6	2.042	.1303
14	64.08	4107.	12.43	4.826	80.44	388.3	2.576	.2072
15	57.07	3257.	9.858	3.035	101.4	307.9	3.248	.3295
16	50 82	2583.	7.818	1.909	127.9	244.2	4.095	.5239
17	45.26	2048.	6.200	1.200	161.3	193.7	5.164	.8330
18	40.30	1624.	4.917	0.7549	203.4	153.6	6.512	1.325
19	35.89	1288.	3.899	.4748	256.5	121.8	8.210	2.106
20	31.96	1022.	3.092	.2986	323.4	96.59	10.35	3.349
21	28.46	810.1	2.452	.1878	407.8	76.60	13.06	5.325
22	25.35	642.4	1.945	.1181	514.2	60.74	16.46	8.467
23	22.57	509.5	1.542	.07427	648.4	48.17	20.76	13.46
24	20.10	404.0	1.223	.04671	817.7	38.20	26.18	21.41
25	17.90	320.4	0.9699	.02938	1031.	30.30	33.01	34.04
26	15.94	254.1	.7692	.01847	1300.	24 02	41.62	54.13
27	14.20	201.5	.6100	.01162	1639.	19.05	52.48	86.07
28	12.64	159.8	.4837	.007307	2067.	15.11	66.18	136.8
29	11.26	126.7	.3336	.004595	2607.	11.98	83.46	217.6
30	10.03	100.5	.3042	.002890	3287.	9.503	105.2	346.0
31	8.928	79.70	.2413	.001818	4145.	7.536	132.7	550.2
32	7.950	63.21	.1913	.001143	5227.	5.976	167.3	874.8
33	7.080	50.13	.1517	.0007189	6591.	4.739	211.0	1391.
34	6.305	39.75	.1203	.0004521	8310.	3.759	266.1	2212.
35	5.615	31.52	.09542	.0002843	10480.	2.981	335.5	3517.
36	5.000	25.00	.07568	.0001788	13210.	2.364	423.0	5 592.
37	4.453	19.83	.06001	.0001125	16660.	1.874	533.5	8892.
38	3.965	15.72	.04759	.00007074	21010.	1.487	672.7	14140.
39	3.531	12.47	.03774	.00004448	26500.	1.179	848.2	22480.
40	3.145	9.888	.02993	.00002798	33410.	0.9349	1070.	35740.

TABLE SHOWING RESISTANCE OF STANDARD SIZES OF WIRE AT DIFFERENT TEMPERATURES
(American Wire Gauge, B. & S.)

Gauge No.	Diameter in Mils at 20° C	Cross-Section at 20° C		Ohms per 1000 Feet					
		Circular Mils	Square Inches	0° C (=32° F)	15° C (=59° F)	20° C (=68° F)	25° C (=77° F)	50° C (=122° F)	75° C (=167° F)
0000	460.0	211 600.	0.1662	0.045 16	0.048 05	0.049 01	0.049 98	0.054 79	0.059 61
000	409.6	167 800.	.1318	.056 95	.060 59	.061 80	.063 02	.069 09	.075 16
00	364.8	133 100.	.1045	.071 81	.076 40	.077 93	.079 47	.087 12	.094 78
0	324.9	105 500.	.082 89	.09055	.096 34	.09827	.1002	.1099	.1195
1	289.3	83 690.	.065 73	.1142	.1215	.1239	.1264	.1385	.1507
2	257.6	66 370.	.052 13	.1440	.1532	.1563	.1593	.1747	.1900
3	229.4	52 640.	.041 34	.1816	.1932	.1970	.2009	.2203	.2396
4	204.3	41 740.	.032 78	.2289	.2436	.2485	.2533	.2778	.3022
5	181.9	33 100.	.026 00	.2887	.3072	.3133	.3195	.3502	.3810
6	162.0	26 250.	.020 62	.3640	.3873	.3951	.4028	.4416	.4805
7	144.3	20 820.	.016 35	.4590	.4884	.4982	.5080	.5569	.6059
8	128.5	16 510.	.012 97	.5788	.6158	.6282	.6405	.7023	.7640
9	114.4	13 090.	.010 28	.7299	.7766	.7921	.8077	.8855	.9633
10	101.9	10 380.	.008 155	.9203	.9792	.9989	1.018	1.117	1.215
11	90.74	8 234.	.006 462	1.151	1.235	1.260	1.284	1.408	1.532
12	80.81	6 530.	.005 129	1.463	1.557	1.588	1.619	1.775	1.931
13	71.96	5 178.	.004 067	1.845	1.963	2.003	2.042	2.239	2.436
14	64.08	4 107.	.003 225	2.327	2.476	2.525	2.575	2.823	3.071
15	57.07	3 257.	.002 558	2.934	3.122	3.184	3.247	3.560	3.873
16	50.82	2 583.	.002 028	3.700	3.937	4.016	4.094	4.489	4.884
17	45.26	2 048.	.001 609	4.666	4.964	5.064	5.163	5.660	6.158
18	40.30	1 624.	.001 276	5.883	6.260	6.385	6.510	7.138	7.765
19	35.89	1 288.	.001 012	7.418	7.893	8.051	8.210	9.001	9.792
20	31.96	1 022.	.000 802 3	9.355	9.953	10.15	10.35	11.35	12.35
21	28.46	810.1	.000 636 3	11.80	12.55	12.80	13.05	14.31	15.57
22	25.35	642.4	.000 504 6	14.87	15.83	16.14	16.46	18.05	19.63
23	22.57	509.5	.000 400 2	18.76	19.96	20.36	20.76	22.76	24.76
24	20.10	404.0	.000 317 3	23.65	25.16	25.67	26.17	28.70	31.22
25	17.90	320.4	.000 251 7	29.82	31.73	32.37	33.00	36.18	39.36
26	15.94	254.1	.000 199 6	37.61	40.01	40.81	41.62	45.63	49.64
27	14.20	201.5	.000 158 3	47.42	50.45	51.47	52.48	57.53	62.59
28	12.64	159.8	.000 125 5	59.80	63.62	64.90	66.17	72.55	78.93
29	11.26	126.7	.000 099 53	75.40	80.23	81.83	83.44	91.48	99.52
30	10.03	100.5	.000 078 94	95.08	101.2	103.2	105.2	115.4	125.5
31	8.928	79.70	.000 062 60	119.9	127.6	130.1	132.7	145.5	158.2
32	7.950	63.21	.000 049 64	151.2	160.9	164.1	167.3	183.4	199.5
33	7.080	50.13	.000 039 37	190.6	202.8	206.9	211.0	231.3	251.6
34	6.305	39.75	.000 031 22	240.4	255.8	260.9	266.0	291.7	317.3
35	5.615	31.52	.000 024 76	303.1	322.5	329.0	335.5	367.8	400.1
36	5.000	25.00	.000 019 64	382.2	406.7	414.8	423.0	463.7	504.5
37	4.453	19.83	.000 015 57	482.0	512.8	523.1	533.4	584.8	636.2
38	3.965	15.72	.000 012 35	607.8	646.7	659.6	672.6	737.4	802.2
39	3.531	12.47	.000 009 793	766.4	815.4	831.8	848.1	929.8	1012.
40	3.145	9.888	.000 007 766	966.5	1028.	1049.	1069.	1173.	1276.

TABLE SHOWING LENGTH OF STANDARD SIZES OF WIRE AT DIFFERENT TEMPERATURES.
(American Wire Gauge, B. & S.)

Gage No.	Diameter in Mils at 20° C	Pounds per 1000 Feet	Feet per Pound	Feet per Ohm					
				0° C (=32° F)	15° C (=59° F)	20° C (=68° F)	25° C (=77° F)	50° C (=122° F)	75° C (=167° F)
0000	460.0	640.5	1.561	22 140.	20 810.	20 400.	20 010.	18 250.	16 780.
000	409.6	507.9	1.968	17 560.	16 500.	16 180.	15 870.	14 470.	13 300.
00	364.8	402.8	2.482	13 930.	13 090.	12 830.	12 580.	11 480.	10 550.
0	324.9	319.5	3.130	11 040.	10 380.	10 180.	9 980.	9 103.	8 367.
1	289.3	253.3	3.947	8 758.	8 232.	8 070.	7 914.	7 219.	6 636.
2	257.6	200.9	4.977	6 946.	6 528.	6 400.	6 276.	5 725.	5 262.
3	229.4	159.3	6.276	5 508.	5 177.	5 075.	4 977.	4 540.	4 173.
4	204.3	126.4	7.914	4 368.	4 105.	4 025.	3 947.	3 600.	3 309.
5	181.9	100.2	9.980	3 464.	3 256.	3 192.	3 130.	2 855.	2 625.
6	162.0	79.46	12.58	2 747.	2 582.	2 531.	2 482.	2 264.	2 081.
7	144.3	63.02	15.87	2 179.	2 048.	2 007.	1 969.	1 796.	1 651.
8	128.5	49.98	20.01	1 728.	1 624.	1 592.	1 561.	1 424.	1 309.
9	114.4	39.63	25.23	1 370.	1 288.	1 262.	1 238.	1 129.	1 038.
10	101.9	31.43	31.82	1 087.	1 021.	1 001.	981.8	895.6	823.2
11	90.74	24.92	40.12	861.7	809.9	794.0	778.7	710.2	652.8
12	80.81	19.77	50.59	683.3	642.2	629.6	617.5	563.2	517.7
13	71.96	15.58	63.80	541.9	509.3	499.3	489.7	446.7	410.6
14	64.08	12.43	80.44	429.8	403.9	396.0	388.3	354.2	325.6
15	57.07	9.858	101.4	340.8	320.3	314.0	308.0	280.9	258.2
16	50.82	7.818	127.9	270.3	254.0	249.0	244.2	222.8	204.8
17	45.26	6.200	161.3	214.3	201.4	197.5	193.7	176.7	162.4
18	40.30	4.917	203.4	170.0	159.8	156.6	153.6	140.1	128.8
19	35.89	3.899	256.5	134.8	126.7	124.2	121.8	111.1	102.1
20	31.96	3.092	323.4	106.9	100.5	98.50	96.60	88.11	80.99
21	28.46	2.452	407.8	84.78	79.68	78.11	76.61	69.87	64.23
22	25.35	1.945	514.2	67.23	63.19	61.95	60.75	55.41	50.94
23	22.57	1.542	648.4	53.32	50.11	49.13	48.18	43.94	40.39
24	20.10	1.223	817.7	42.28	39.74	38.96	38.21	34.85	32.03
25	17.90	0.969 9	1 031.	33.53	31.51	30.90	30.30	27.64	25.40
26	15.94	.769 2	1 300.	26.59	24.99	24.50	24.03	21.92	20.15
27	14.20	.610 0	1 639.	21.09	19.82	19.43	19.06	17.38	15.98
28	12.64	.483 7	2 067.	16.72	15.72	15.41	15.11	13.78	12.67
29	11.26	.383 6	2 607.	13.26	12.46	12.22	11.98	10.93	10.05
30	10.03	.304 2	3 287.	10.52	9.885	9.691	9.504	8.669	7.968
31	8.928	.241 3	4 145.	8.341	7.839	7.685	7.537	6.875	6.319
32	7.950	.191 3	5 227.	6.614	6.217	6.095	5.977	5.452	5.011
33	7.080	.151 7	6 591.	5.245	4.930	4.833	4.740	4.323	3.974
34	6.305	.120 3	8 310.	4.160	3.910	3.833	3.759	3.429	3.152
35	5.615	.095 42	10 480.	3.299	3.101	3.040	2.981	2.719	2.499
36	5.000	.075 68	13 210.	2.616	2.459	2.411	2.364	2.156	1.982
37	4.453	.060 01	16 660.	2.075	1.950	1.912	1.875	1.710	1.572
38	3.965	.047 59	21 010.	1.645	1.546	1.516	1.487	1.356	1.247
39	3.531	.037 74	26 500.	1.305	1.226	1.202	1.179	1.075	0.9886
40	3.51	.029 93	33 410.	1.035	0.9725	0.9534	0.9350	0.8529	.7840

(For further tables, showing diameters in millimeters etc. see Circular of the Bureau of Standards Number 31, Copper Wire Tables, obtainable at the Government Printing Office, Washington D. C. @ 20c.)

CHAPTER 7

Electromagnetic Induction

Magnetic Retentivity—History of Electromagnetic Induction—The Transformer—Alternator—Early Attempts to Develop Wireless Telegraphy, with Low-Frequency Induction—Induction Used for Guiding Moving Vehicles

71. The phenomenon which takes place when *magnetism* is conveyed from a natural magnet to a piece of iron or steel, making that metal in turn magnetic, is called *magnetic induction*. It is discovered that the magnetic lines of force of the first magnet permeate the second material, causing it to develop magnetic lines of force of its own, which it retains for a long or short period according to its degree of permeability and its *retentivity*. The electromagnetic lines of force surrounding a magnet can be made to induce the flow of an electric current; and an electric current can be made to set up magnetic lines of force exactly corresponding to those of a permanent magnet. In other words, *electromagnetic induction* works both ways, from magnetism to current and from current to magnetism. In paragraphs 29 to 34, the electromagnet is explained, showing how the magnetic lines of force surround a solenoid, and that the polarity of the solenoid depends on the direction of the winding of the coil as well as upon the direction of the current through it.

72. The discovery of the magnetic properties of a solenoid is usually attributed to Sturgeon, of England, in 1824. In 1831 Faraday performed an experiment which became famous, and from which the *practical application of electromagnetic induction* may be said to date. Faraday's experiment consisted of revolving a copper disc, connected in series with a galvanometer, between the ends of a strong horseshoe magnet, and it proved that *the magnetic field surrounding the horseshoe induced an electric current into the second circuit as long as the disc was kept moving, but that there was no current induced when the disc stood still.* When the disc was rotated in the direction indicated by the arrow, the negative end of the circuit was at the upper terminal of the wire, and when the disc was rotated in the opposite direction, the negative was the end attached to the pan of mercury.

He then applied the same principle to magnets and charged solenoids, moving them by hand. When a strong bar magnet is inserted into a solenoid which is connected in series with a

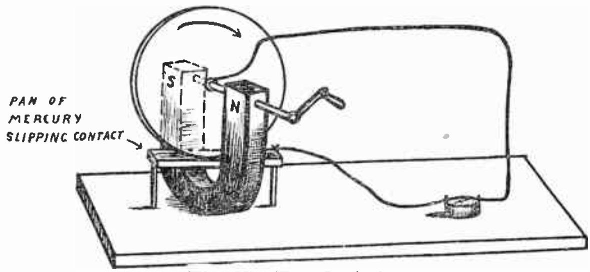


Fig. 37. Faraday's Disc.

galvanometer, these will be one deflection of the galvanometer needle for each movement of the magnet. The same phenomenon will take place when a coil of wire connected to a source of power is inserted into the secondary circuit;

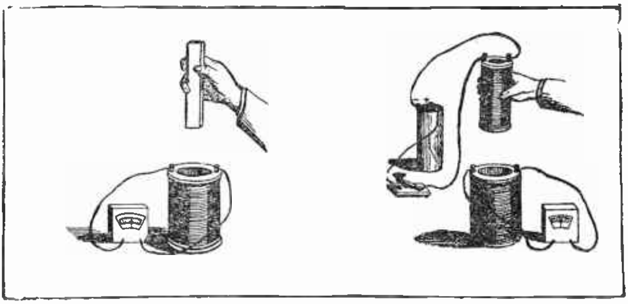


Fig. 38. Electromagnetic Induction.

or, if we leave the charged coil inserted inside of the second coil, and continually make and break the circuit with a key or switch, the same induction will take place.

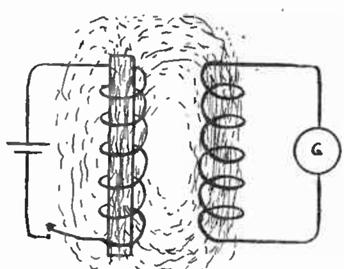


Fig. 39. Electromagnetic Induction.

73. As the magnet from which electric current is induced into the secondary circuit does not actually touch the secondary coil, it is proved that it is not the moving of the bar of metal or the electromagnet itself, but the *changing of the relation, or cutting through of its magnetic lines of force, that causes the current to move in the secondary circuit.* This might be likened to the action of a water wheel in the water. So long as the wheel is motionless, it is only a wheel standing in the water. The water and the wheel are exactly the same substances as when in motion; but as long as the wheel is idle it has no effect on the water. When the wheel *moves* in the water it immediately becomes a *source of power* that forces the water to flow before it. A magnet and a coil of wire at rest are merely sources of *potential energy* lying idle. When the magnet is *moved* it becomes a source of power and the electricity that has been dormant suddenly becomes a current traveling along the path provided for it.

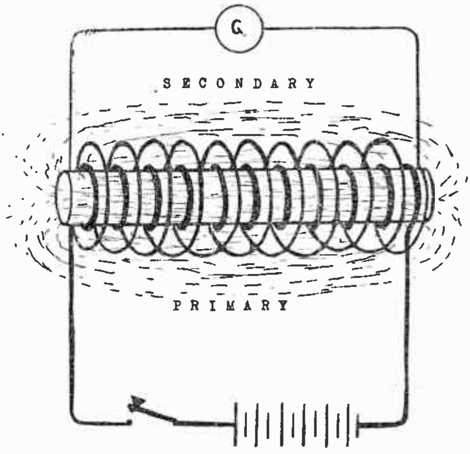


Fig. 40. Transformer.

74. We find later, that if we cause a *change in the relation* between the *primary* and *secondary* coils, by *changing or varying the direction of the current itself, while leaving the coils stationary, that the effect is the same as when either the primary or secondary coil or magnet is moved.* We find that *a movement of the lines of force* around the *primary coil* will *induce current* to flow through the *secondary coil* and around the secondary circuit. This may be accomplished by use of the key, as mentioned above, or by sending a pulsating

or an alternating current through the primary coil. When we thus induce a current into the secondary circuit by reversing the electromagnetic field around the primary, the current induced into the secondary will also continually reverse its direction corresponding to the rising and falling primary current, but in the opposite direction. A device consisting of two coils of wire wound in inductive relation to each other for the purpose of transferring energy from one to the other is known as a transformer.

The voltage of the secondary circuit depends upon the ratio of the turns of wire in the secondary winding to those in the primary. When there are more turns of wire in the secondary coil, the voltage is stepped up and we have a step-up transformer. When there are less, we have a voltage decrease, and a step-down transformer.

75. When the secondary of an iron-cored transformer is open, little current flows through the primary, due to the back pressure of the strong magnetic field set up in the core. When the secondary circuit is closed, placing a load on the primary, the current of opposite polarity in the secondary reduces the magnetism of the core, permitting the primary to draw more current. While the *voltage* may be *stepped up* to many thousand times that of the primary, there is always a proportionate *decrease in current,* so that, with a small power loss due to heat and eddy currents, the *total power* in the secondary must be somewhat less than the total power in the primary circuit.

76. If instead of moving a magnet in and out of a coil of wire, as in figure 38, we hold the magnet stationary, and move a loop of wire connected to a galvanometer around the end of the magnet, the needle of the galvanometer will indicate the presence of a current. If we reverse the polarity of the magnet, the current will flow through the wire in the

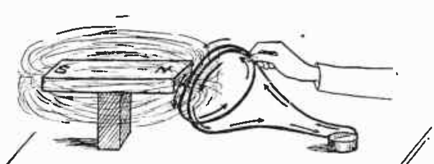


Fig. 41. A Loop of Wire Moved Upward Through a Magnetic Field. Current from Negative to Positive, and at Right Angles to Magnetic Lines of Force.

opposite direction. Or if we place a loop of wire between two magnets of opposite polarity, provide it with slipping contacts to an external circuit, and rotate the loop by mechanical means, the loop will pick up current from first one magnet and then the other as it revolves between them, and we will have a supply of alternating current in the external circuit. This is the fundamental principle of the alternating-current generator, or alternator.

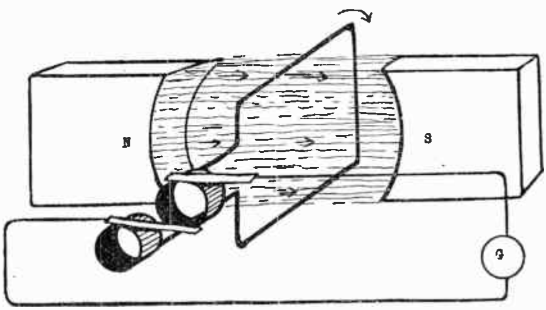


Fig. 42. A Loop of Wire Revolved Between Two Alternate Magnetic Fields.

77. When we cause a coil to be revolved inside of a magnetic field, we transfer or transform, mechanical energy into *electrical energy.* Some form of *energy* is always required to cause electric current to *flow.* When we insert the magnet into the solenoid, for instance, more energy is exerted when the magnet is connected to the circuit containing the galvanometer than when not so connected, because of the induced current. *Current produced by electromagnetic induction is invariably in such a direction that the magnetic lines of force surrounding it have a tendency to stop the motion of the current producing them.* This is known as *Lenz's Law.* It is a demonstration of the law of conservation of energy; and has several practical applications.

78. The discovery of the above simple facts may be rated as of first importance in the history of electricity. The International Encyclopedia gives the following information: "Many of the most important facts in electricity which were made known during the 19th century by Coulomb, Ohm and Faraday, were in reality discovered by Henry Cavendish (1731-1810), one of the world's greatest philosophers. Fara-

day originated the idea of *lines of induction* and established their laws; he also explained the attraction and repulsion of bodies caused by electrical or magnetic forces as due to the *relative* properties of these bodies and the surrounding medium. Clerk-Maxwell expressed Faraday's experimental discoveries in mathematical language and formulæ and advanced the theory of electricity which is the basis of all modern theories." The induction coils, generators, motors, power transformers and endless variety of electrical machines and radio apparatus in common use today embody practical applications of the fundamental laws of electromagnetic induction discovered by these pioneers. Many of the early experimenters attempted to establish wireless telegraph communication based on the principle of low-frequency *electromagnetic induction* between loops of wire. They found it impracticable for distances of more than a few feet. Aeroplanes, and sometimes vessels, are today making use of this kind of *induction* to guide them to landing places, or into harbors in the fog. The moving object carries loops of wire which pick up current from a buried or submerged cable charged with high-potential alternating current; and this is indicated by suitable apparatus, and the position determined.

CHAPTER 8

The Induction Coil

Primary Spark Coil — Secondary Induction Coil — Interrupters — Marconi's First Radio Transmitter—Dr. Mahlon Loomis's Drawings Showing Induction Coil

79. Induction coils may be divided into two classes, those consisting of a primary winding only, and known as *primary induction coils,* and those having a secondary coil, known as *secondary induction coils.* The primary induction coil, or *"jumping spark coil,"* is not used in radio work; but is confined to ignition purposes. When battery current is sent through the turns of wire composing the coil, the magnetic lines of force unite and form one continuous magnetic flux, as in figure 14. The core may consist of one bar of iron; but it is generally made of a bundle of pieces of soft iron wire, which has a greater permeability than the solid bar and also reduces loss of power due to stray or eddying currents, which are sometimes set up in the core. A simple vibrator is placed in series in the circuit with the coil. The vibrator usually consists of a small strip of spring steel with an iron button at one end, and two small solid silver contact buttons, one placed on the side of the spring opposite to the larger iron button, and the other one stationary. When current flows through the coil, with the silver contacts closed, the magnetism induced into the coil and the core by the electric current attracts the iron button, and the steel spring bends toward the end of the core of the coil. This breaks the circuit, for that instant, so that no current flows. As the open in the circuit also shuts off the source of magnetism, the spring is released and springs back, making contact with the stationary part of the vibrator, thus closing the circuit and allowing current to flow through the coil, producing a magnetic flux, attracting the steel spring toward the core, again breaking the circuit, etc., etc., many times per second, say anywhere from 30 to 100 times. The stationary part of the vibrator is adjusted by a screw, so that the distance between the contacts can be regulated. This rapid making and breaking of the circuit at the vibrator causes a fat spark between the contacts. No transformer action takes place, of course, as there is no secondary. The voltage remains the same. The apparatus is called an induction coil on account of the magnetic induction taking place between the separate turns of the solenoid. This is

known as *self induction.* This type of spark coil, if placed in the proper location for taking advantage of the spark, can be utilized for igniting gas, or gasoline engines.

80. By use of the same vibrating apparatus and the addition of a secondary coil equipped with a sparking gap, or open in the circuit generally called a *spark gap,* the fat spark will jump between the contact points of the vibrator as before; but we will also get a much stronger spark across the spark gap in the secondary. This secondary spark is brilliant "electric blue" in color and makes a crackling noise. This is on account of the greatly increased voltage of the secondary. Direct current will not produce this kind of a spark. (It may jump a gap once and then stop, or it may continue across the break in a wire, or a short-circuit between two wires, in the form of an *arc,* which may do considerable damage setting fire to nearby combustibles.) The

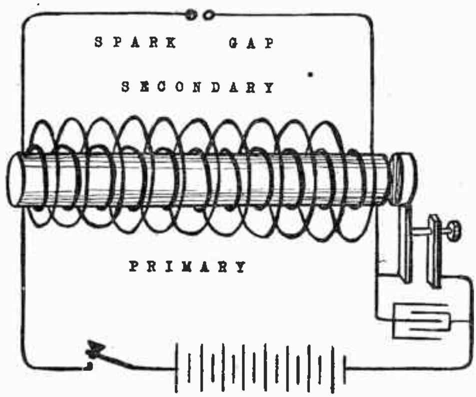


Fig. 43. Induction Coil with Magnetic Interrupter.

type of interrupter described above is known as a magnetic interrupter. It is possible to make and break the contact of the circuit by other means; and so long as this is done with rapidity and regularity, the results are the same. A mechanical method of interrupting the circuit with a secondary coil, or transformer type of induction coil, is used on many automobiles for ignition purposes.

81. The induction coil formed the basis of the earliest Marconi radio transmitter patents of 1896 and the years

immediately following. The induction coil was invented by Ruhmkorff, of Russia, in 1851, and is sometimes called a Ruhmkorff coil. It was improved during the following year by Fizeau, who added a condenser across the vibrator. The

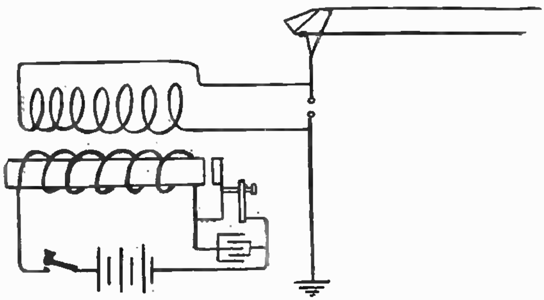


Fig. 44. Simplest Possible Induction Coil Radio Transmitter.

condenser consists of several alternate layers of tinfoil and some insulating material such as "empire cloth," or heavily waxed paper. The strips of tinfoil and insulating material are piled so that one set of alternate strips of tinfoil are connected to one terminal, and the other set of alternate strips are connected to the other terminal; and the two sets of strips of conducting material do not touch each other at any point. Direct current can not pass through a con-

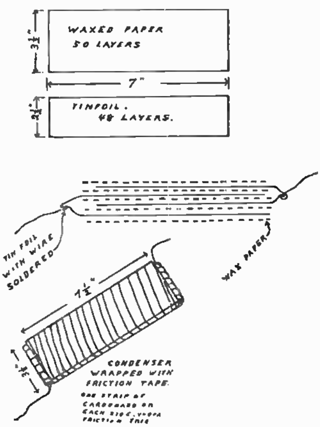


Fig. 45. A Working Drawing for an Induction-Coil Condenser.

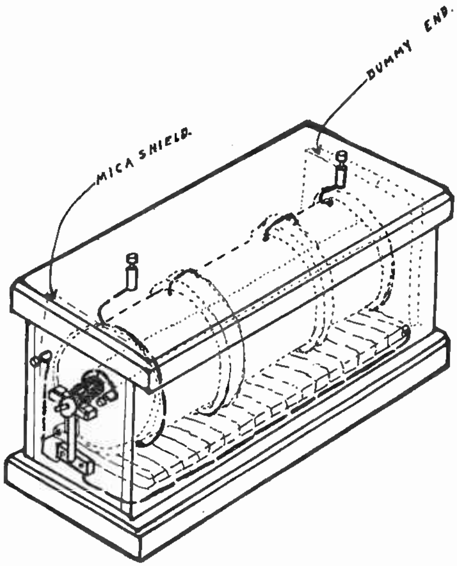


Fig. 46. A Working Drawing Showing Completed Arrangement of Coils and Condenser of Induction Coil Inside of Box.

denser, as these plates, or strips, do not touch. When current reaches either one of the terminals of the condenser, a condition of electrical strain is created between the two sets of plates, and when this strain is relieved, the electrical energy stored in the condenser at the instant of charging will discharge in a direction reverse to the charging influence. (Condensers are treated more thoroughly in Chapter 17.) When the contacts of the vibrator touch, and cur-

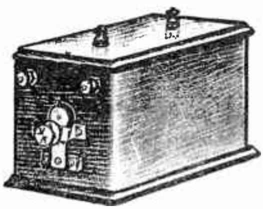


Fig. 47. Commercial Type of Inductance Coil with Magnetic Interrupter.

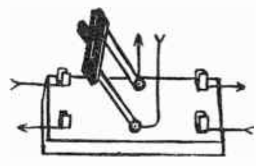


Fig. 48. Double-Pole Double-Throw Switch.

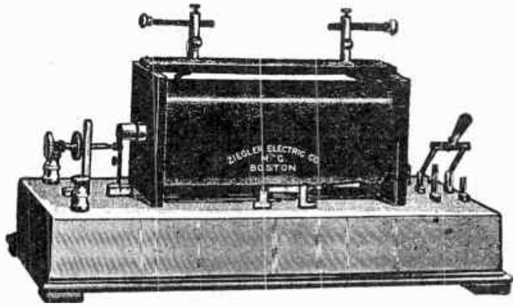


Fig. 49. A Laboratory Type of Induction Coil, Showing Spark Gap and Switches for making Different Power Connections.

rent is flowing through the coil, the condenser is short-circuited. When the contacts are separated, the E. M. F. induced in the primary of the coil by self induction is not forced to completely overcome the resistance of the space between the silver contacts, but it charges the condenser, thus hastening the demagnetizing process of the solenoid and core, as the condenser discharges immediately in the direction opposite to that of the current which charged it. This results in a saving of the silver contact points, which without the condenser melt very soon from the heat of the spark, and also greatly increases the voltage of the secondary circuit. In most factory-built induction coils the condenser consists of several strips of tinfoil and waxed paper several feet long, the whole being *rolled* into a compact cylinder. The coil and condenser are usually imbedded in an insulating composition.

82. Induction coils are sometimes operated with an electrolytic interrupter. There are various makes of these interrupters on the market, the underlying principle being the same. One well-known type is the Wehnelt electrolytic interrupter. It consists of a jar of dilute sulphuric acid (H_2SO_4), in which are immersed two electrodes, somewhat similar to the chemical cell. The active electrode consists of platinum, or an alloy containing platinum, in the form of a thin pencil, which is protected from the acid, except at its very point, by a glass tube. The other electrode is lead. The platinum electrode is connected to the positive side of

the current on which the induction coil is being operated; and as the current flows, the chemical action thus set up causes bubbles of oxygen to accumulate on the platinum point. These bubbles completely insulate this point from the electrolyte, and stop the flow of current. When the current is interrupted, the bubbles settle into the liquid, thus closing the circuit, and allowing the same process to be repeated. This type of interrupter is suited for use with a high-voltage primary current, and is conveniently employed in connection with a 110-volt city power line. If the source of power supply is alternating current, the interrupter will work equally well when connected either way, as it then acts as a rectifier as well as an interrupter; but, if used with direct current, it will operate only in the one direction indicated. The speed of this interrupter is greater than that of the magnetic interrupter. It depends upon the size of the exposed platinum point, the voltage of the current sent through it, and also upon the amount of back pressure set up in the coil by the self induction.

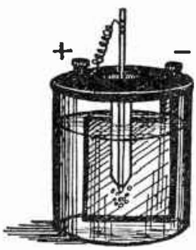


Fig. 50. Electrolytic Interrupter.

83. When the current in the primary of a transformer is a true alternating current, that in the secondary will also be alternating in character; but when the current in the primary consists of an interrupted direct current, the current induced into the secondary by these pulsations will have a greater amount of current in one direction than in the other. However, by varying the magnetic field of the primary coil we set up in the secondary a continually reversing current which is generally regarded as an alternating current. Induction coils are rated commercially by the length of the spark, or the maximum distance that current can be made to jump across the spark gap. This ranges from one-fourth of an inch to six or seven inches, according to the construction of the apparatus. The secondary winding of commercial induction coils is usually wound in two or three separate sections, sometimes called "pies." This is done for convenience in handling or repairing.

When an induction coil is equipped with an additional condenser in the secondary circuit, and an air core transformer between the condenser circuit and the antenna circuit, we have a complete radio transmitter, which radiates electromagnetic waves to a distance in proportion to the power on which it is operated. Figure 51a shows the four circuits of an early Marconi transmitting apparatus. The primary of the induction coil, batteries and key form the first circuit. The secondary and spark gap form the second, or secondary, circuit. The condenser and the spark gap and the primary of the air-core transformer the third circuit, and the antenna system the fourth circuit. The operation of the condenser in the third circuit greatly increases the brilliancy of the spark, and the transmitting efficiency of the apparatus.

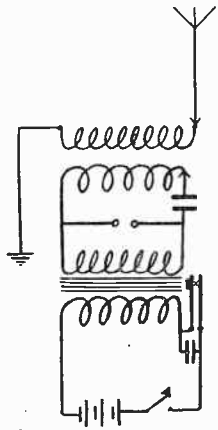


Fig. 51a. Marconi "Four-Circuit Transmitter.

Figure 51b shows an earlier form of the Marconi transmitter. Regarding this, the patent specification states that "a is a battery, b a Morse key for closing the circuit through the primary of a Ruhmkorff coil," that c′c′ which represent the terminals of the secondary are attached to two metal balls inside of a piece of insulating tubing which is filled with vaseline or oil, ee are two additional balls which may be omitted if desired, d^4 represents mechanism by which the distance between the sparking balls may be adjusted, f represents a "cylindrical parabolic reflector made by bending a metallic sheet of brass or copper to form, and fixing it to metallic or wooden ribs f′." The diagram at the lower part of figure 51b shows a sheet of metal elevated to form an antenna, and an earth connection. The spark gap is then placed directly in series with the antenna and ground, across the secondary of the induction coil. The induction-coil radio transmitter is now obsolete, except for use in cases of emergency. For several years the standard type of sending apparatus consisted of a "spark set," which was practically the same as that shown in figure 51a, except that it employed an alternator for the input of the transformer primary, instead of the vibrator interrupted battery current.

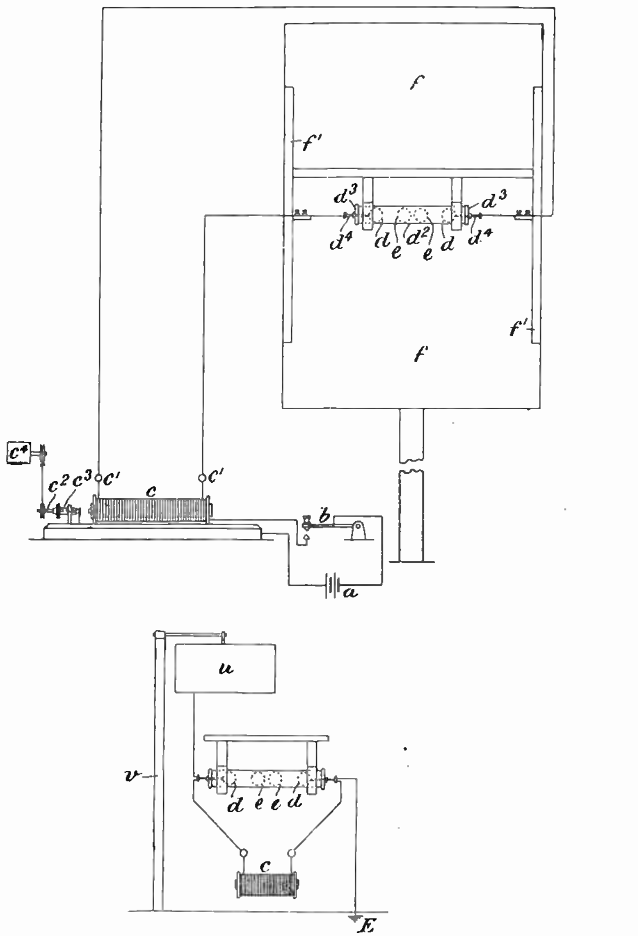


Fig. 51b. Reproduction from Marconi Patent No. 586,193 of July 13, 1897.

It appears, from the notes and drawings of Dr. Mahlon Loomis, that he had conceived the idea of using a buzzer or induction coil in series with his antenna and ground, but of course he did not develop the idea commercially.

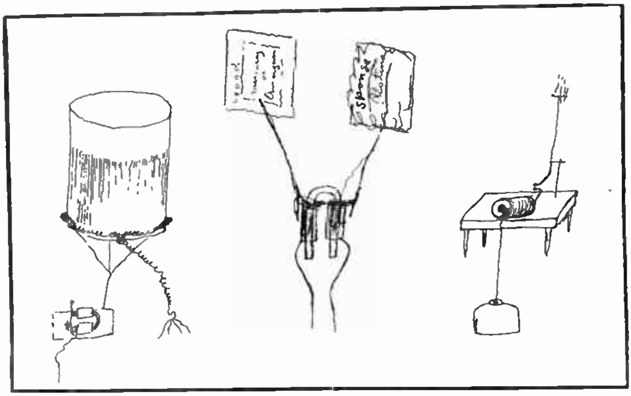


Fig. 51c. Reproductions of Drawings Made by Dr. Mahlon Loomis. (See Manuscript Division of Library of Congress, Washington, D. C.)

CHAPTER 9

The Alternator

Fundamental Principle of Revolving-armature Alternator—Sine Wave—Rule for Frequency of Alternator—A. C. Magneto—Alternator Armature—Revolving-field Alternator—Inductor Alternator—Inductor-Alternator Radio Transmitter

84. In chapter 7, figures 41 and 42, the fundamental principle of the alternator is illustrated. The alternator consists essentially of a loop of wire connected in series with an external circuit, and a magnetic field which is provided either by strong permanent magnets or by electromagnets; and the two are arranged mechanically so that either one or the other can be revolved so as to obtain that cutting of the magnetic flux necessary for the process of electromagnetic induction. The coil of wire connected to the external circuit is called an *armature,* and the part of the machine which provides the magnetic field is called the *field.* When the field consists of two or more electromagnets of opposite polarity, the cores are called *field poles,* and the windings *field windings.*

85. The earliest known generator was Faraday's disc, figure 37. In this the disc was the armature, and the opposite ends of the horseshoe magnet were the field poles. Nowadays an *armature* is generally understood to be a *loop or coil of wire* used in inductive relation to field poles, and connected to an external electric circuit. In the simple revolving-loop alternator, illustrated in figure 42, the direction of the coil is indicated by an arrow. With the loop in the position shown in figure 42, *the magnetic lines of force cut the loop; but there is no E. M. F. induced into the loop. As the loop turns to a horizontal position, cutting through the magnetic field, an E. M. F. is induced, which causes current to flow in one direction.* The loop, having revolved one-quarter of a circle, has reached the horizontal position, is parallel to the lines of force, and has *picked up the maximum E. M. F. possible* with that particular combination of devices composing that particular machine. As the loop continues revolving and finishes the first half of a complete revolution, the induced E. M. F. decreases, until the loop is again in the vertical position, and the E. M. F. is zero. Thus, *one rush of current* picked up by induction, and caused to move by the E. M. F. set up in the armature as current

is induced into the secondary coil of a transformer, *flows through the external circuit.* The slipping contact which makes this possible consists of two conducting rings, insulated from each other, on which rest two "brushes." The rings are called collector rings, as they collect the current generated and pass it along to the rest of the circuit. The *current* delivered to the external circuit for the one-half revolution of the armature will *rise to maximum amplitude and then fall to zero,* as the armature reaches the different angles of the circle which place it in a corresponding relation to the magnetic field. Then when the loop continues the other

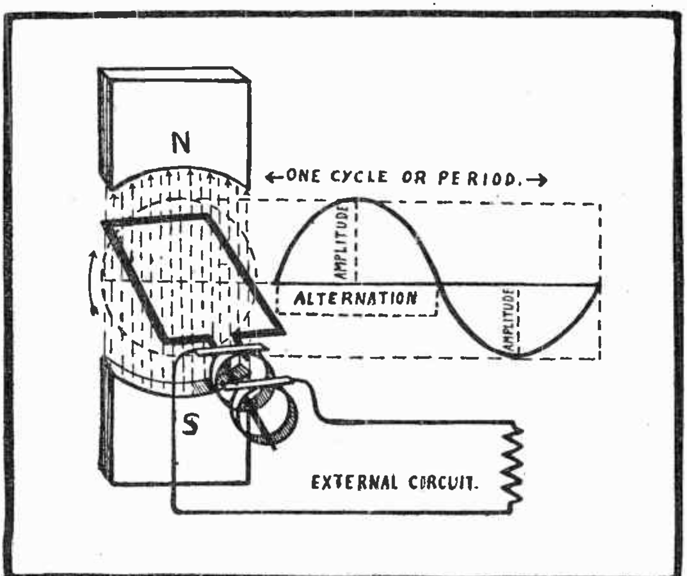


Fig. 52. Simple Revolving-Armature Alternator, and Sine Curve Indicating Amplitude of Current in Opposite Directions.

half of the revolution the process is repeated, only this time, on account of each side of the loop cutting the magnetic field in a direction opposite to the way it cut them during the first half, the *current flows in the opposite direction. It rises to maximum amplitude, and falls to zero throughout the coil and the entire external circuit, in the opposite direction.* Thus we have generated an *alternating current.* The complete revolution of the armature, as it travels completely through one circle, is represented by the sine curve. This is called one *cycle.* Each half revolution, which produces one-half cycle, is called one *alternation.* The period of *time* required for the cycle is termed the *period.* Alternators seldom produce a current of perfectly symmetrical sine wave, but the sine wave is the fundamental premise on which the theory of alternating current is based, due allowance being made for variations in the shape of the wave.

86. Just as inserting an iron core into a simple solenoid increased the magnetic field surrounding it, by making a magnet of the core, we find that placing an iron core inside of the revolving armature increases very greatly the current induced into the secondary circuit; and as increasing the number of loops of wire in the secondary of a simple transformer increased the E. M. F. in that circuit in direct ratio, we find that increasing the number of turns of wire in this revolving armature will do the same thing. So, we may say that *the E. M. F. generated will be in proportion to the strength of the magnetic field, or its number of lines of force, and the length of wire and number of turns composing the armature, and the number of times that the armature cuts the lines of force.* Or, in other words, upon the *rate of cutting the lines of force.* Alternators are rated commercially according to the output, or the *power* which they will produce, and the *number of cycles per second.* For instance, the reading on the name plate attached to the alternator furnished with a Marconi ½-K. W. radio transmitter is as follows: .5 K. W., 120 cycles, 125 volts, 5 amps. (Note.—While E × I gives 625 watts, this is rated as a ½-K. W. machine.)

87. The rule for the *frequency of an alternator,* or its number of cycles per second, is

$$\text{Frequency} = \frac{\text{Number of field poles} \times \text{revolutions per second.}}{2}$$

The revolutions per second multiplied by the number of field poles give you the number of alternations, and one-half of this number is the *number of cycles.* A small loop revolved by hand, naturally would be of low power and low frequency. Where any amount of power is desired, or a small amount for any length of time, it is advantageous to turn the rotating portion of the machine by some mechanical means. This may be done by water power, steam power, gasoline engine, or an electric motor. When the turning power is furnished by these means, it is easier to control the speed of the machine, and the frequency will be more nearly constant, according to the regularity of the turning power. An alternator having two poles is called a *bipolar machine.* It is possible to increase the number of poles and still have the frequency of the current generated comply with the above

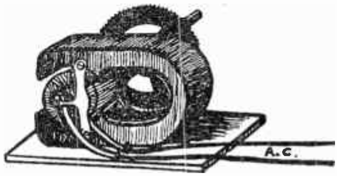


Fig. 53. Simple Magneto.

rule. While the armature may not completely turn over, if by passing through alternate fields successively it will produce one cycle, the principle is the same. The number of poles must always be of an equal number; and the armature usually consists of series-connected coils wound in alternate polarity, one armature coil for each field pole. In some types of alternators there is one armature coil for each pair of field poles, and an open space left between these on the armature core. This is called a half-coil armature winding. It is convenient for polyphase, but has no advantage for single-phase machines. The simplest application of the principle of generating electric current for practical purposes is the magneto, so called because its fields are simply permanent magnets. It has, however, an armature consisting of several turns of wire wound around an iron core.

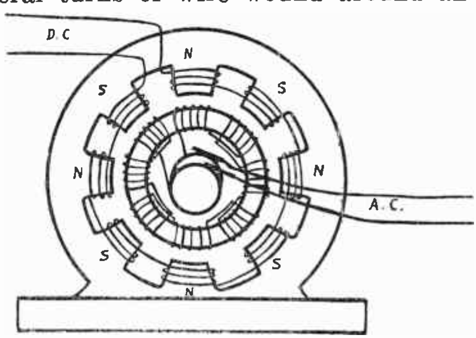


Fig. 54. Circuits of an Eight-Pole Single-Phase Alternator with Revolving Ring-Wound Armature.

Otherwise it is the same as figure 52. Low-powered magneto alternators are used for ringing telephone bells, where the alternating polarity of two electromagnets causes the clapper to vibrate; and for igniting gasoline engines. When the alternator is operated with electromagnets for fields *the current exciting them must be direct.* It may be provided by a bank of storage batteries, or a direct-current generator. This is known as a separately-excited field.

88. The armatures used differ in various makes of machines. The early form generally consisted of a hollow ring mounted on a shaft. The first practical alternator, ring wound, is believed to have been built in 1860 by Antonio Pacinotti, of Italy. Most of the later machines have armatures wound over a core shaped like a drum, and called drum armatures. However, the core is not a solid piece of metal, but composed of many thin sheets, or laminations, for the purpose of reducing loss from hysteresis and eddy currents.

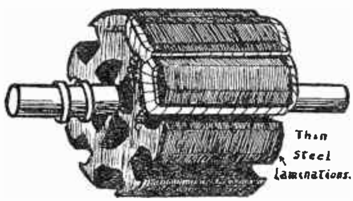


Fig. 55. Modern Type of Revolving Armature.

The arrangement of the wires in armature windings is considered a trade by itself, although any electrician should have some understanding of the most common types. Windings for alternators are not as complicated as those used for direct-current generators.

89. Some alternators are built with the armature attached in a stationary position on the inside of the frame, and have the field magnets fastened to the shaft and revolved. The stationary armature is then generally referred to as a *stator*, and the field as a *rotor*. The electromagnetic principle and the result are exactly the same as with the revolving armature and stationary field poles. In this type of machine the revolving field poles are connected to an external source of power by means of slipping contacts, and the connections to the output circuit of the alternator are stationary.

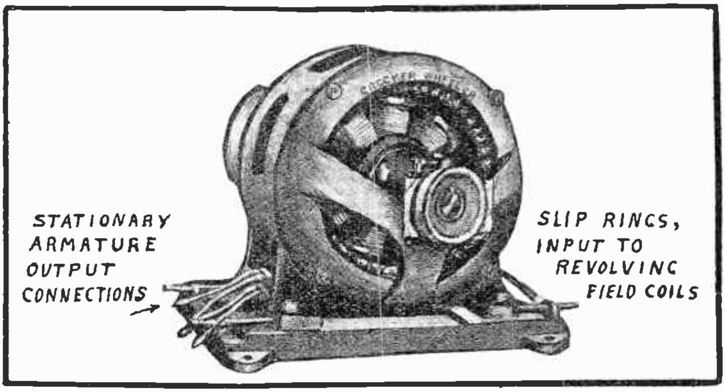


Fig. 56. Crocker-Wheeler Revolving Field Alternator.

90. A third type of alternator consists of a machine having both the armature and field winding stationary. It is operated by interrupting the magnetic flux between sections of the iron armature core, by rotating a disc which offers alternately conducting and insulating materials which pass or stop the lines of force. This is called an *inductor alternator,* and the wheel or disc is known as an *inductor.* When the principle is applied to low-frequency machines the inductor consists of a heavy toothed wheel, the air between the teeth acting as the insulating material. Inductor alternators are made for extremely high frequencies, in which case the inductor is made of very fine steel, heavy at the center but thin at the edge; and having small square holes through it near the edge, which are plugged with phosphor bronze. The steel conducts the magnetic lines of force, but phosphor bronze, being a non-magnetizable material, reduces the strength of the magnetic field through which it rotates. The field coil is wound over a continuous iron core, through which the magnetic lines of a force pass. The armature is not actually a coil, but rather a continuous wire arranged in a wave-shaped form on the frame. At the instant that the air gap, or phosphor bronze, passes through the path of the magnetic flux, between the spaces left in the armature arrangement, there is a fall in the magnetism in the armature winding. As the disc rotates,

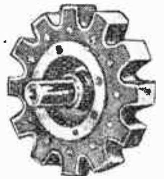


Fig. 57. Inductor of Low - Frequency Inductor Alternator.

the magnetic flux varies periodically, rising to maximum and falling to minimum, but not reversing its polarity. This causes periodic undulations in the magnetic field of the stationary field winding. This undulating magnetic field induces a periodically reversing emf. in the stationary armature, and an alternating current flows in the output circuit. On account of the magnetic flux through the armature core being of an undulating character, twice as many armature turns of wire are necessary to produce a given voltage as would be required if the magnetic flux in the armature core reversed its polarity.

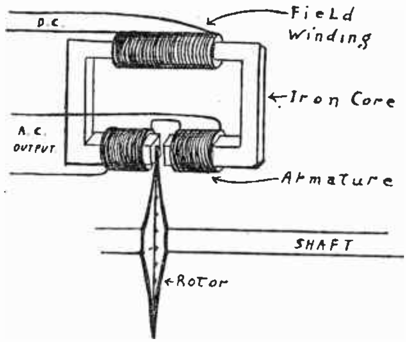


Fig. 58. Method of producing alternating Current with an Inductor.

91. Frequencies of ordinary commercial types of alternators are generally 60, 120, 240, 500 or 600 cycles. These are low frequencies. Any frequency over 10,000 is rated as "high frequency." Inductor alternators are constructed which produce from 10,000 to 200,000 cycles per second. It is possible to employ a high-frequency inductor alternator as the main part of a radio transmitter, with very little else in the way of apparatus as compared to some other methods. Figure 59 illustrates such an apparatus. The rotor is turned by a motor driven by 110 volts direct current. The field is excited from the same source of power. The high-frequency current is conveyed to the antenna circuit by way of the transformer, and undamped electromagnetic waves are radiated for purposes of communication, whenever the key is pressed. More elaborate methods are necessary when high power is used. For instance, it is better to have the key inductively connected to the circuit. High-frequency alter-

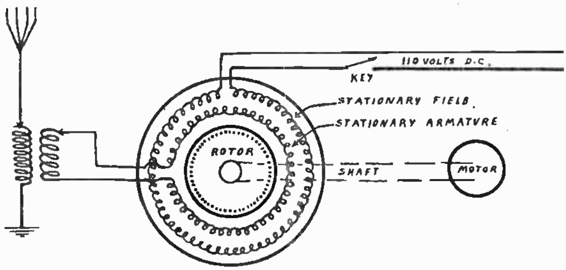


Fig. 59. Fundamental Diagram of Connections of Inductor-Alternator Radio Transmitter.

nators are considered, in connection with other means for producing continuous waves, in chapter 31.

The type of alternator employed most frequently with the "spark" transmitter is the revolving armature machine with either four or six field poles. Alternators used for generating current for supplying city power lines are generally of the revolving-field type, such as illustrated in figure 84.

CHAPTER 10

Alternating Current

Generation of Alternating Current — Back emf. — Mutual Induction — Simple Harmonic Motion—A. c. Effective Value—A. c. Phase Angle—Power Factor—Kva.—Three-Phase Current—A. c. Power Line—A. c. Skin Effect—Table of A. c. Symbols

92. Alternating current has been defined in previous chapters, and referred to in a general way. It has many characteristics not met with in direct current. Direct current without the slightest pulsation may be produced by chemical action. Direct current having more or less of a pulsating nature may be produced in different ways. *Alternating current is invariably generated by induction from magnetic fields of alternate polarity in conjunction with motion.* And the current continually and with regularity alternates its direction exactly in proportion to the changes in polarity of the magnetic field from which it is induced. Such currents are sometimes called induction currents, and the devices operated on alternating current called induction machines. For instance, alternating-current motors are called induction motors, although there are finer distinctions for the various types, because their turning depends upon the changing polarity of the current induced into their rotating coils.

93. On account of the constantly changing direction of the magnetic flux surrounding a wire charged with alternating current, we find an *opposing force.* There is a tendency of the changing flux to oppose the flow of the current; and what is called a "back emf." is built up. When a solenoid is charged with alternating current, the cutting of the wires composing it, by the constantly reversing magnetic flux, re-induces magnetism which is stored up in the solenoid. This property is called *inductance,* or *self-induction.*

94. When two coils of wire are arranged in inductive relation to each other, and alternating current sent through one of them, inducing alternating current into the secondary coil also, the magnetic lines of force surrounding the secondary coil passing over the turns of wire composing the primary, re-induce magnetism back into the primary. This additional energy may be re-induced back into the secondary again, and so on, as long as there is magnetism in either coil to

induce lines of force into the other coil. This is called *mutual induction.*

95. In figure 52 a simple revolving armature alternator is illustrated, with the *sine curve.* This curve is used to typify the various stages of rising and falling E. M. F. and amplitude of current in each alternation. It is the sine, or sinusoid curve, commonly used in trigonometric problems, as one of the functions of a circle and, in the plotting, is drawn on a paper marked off in small squares. The curve plotted on the ruled paper represents *rising and falling E. M. F. and amplitude plotted against time.* A helpful illustration of the sine is shown in figure 60, where it is used

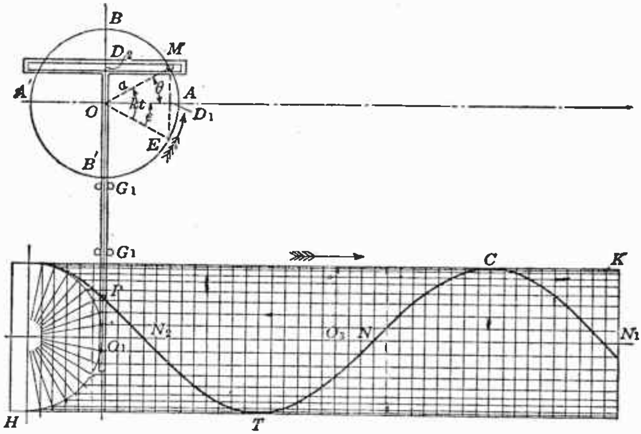


Fig. 60. "Mechanical Generation of Simple Harmonic Motion, and of a Simple Progressive Wave."
(Courtesy of Slichter's Mathematical Analysis.)

to typify simple harmonic motion. The following quotations from *Slichter's Mathematical Analysis* explain the figure. "Examples of simple harmonic motion are the bob of a pendulum, a point in the prong of a vibrating tuning fork, a point in a vibrating violin string, the particles of air during the passage of a sound wave. The motion is oscillatory in character and repeats itself in definite intervals of time. Let a uniformly rotating wheel, O A B, be provided with a pin, M, attached to its circumference and free to move in the slot of the cross-head as shown, the arm of the cross-head being restricted to vertical motion by suitable guides,

G_1 G_1. Then, as the wheel rotates, any point, P, of the arm of the cross-head describes *simple harmonic motion* in a vertical direction. The *amplitude* of the simple harmonic motion is the radius of the circle, OB; its *period* is the *time required* for one complete revolution of the wheel."

96. On account of the rising and falling alternations, the *effective* value of an alternating current is not equal to its value at maximum or zero. When an alternating-current ammeter gives a reading of 10 amperes, the alternations are varying between zero and 14.1 amperes. Or, if the ammeter were to read 7.07 amperes, the alternations would be varying between zero and ten amperes. This is a reading of the *effective value* of the current. Also the E. M. F. rises and falls with each alternation, and it is the *effective value of the voltages varying between zero and maximum* which is registered in the alternating-current voltmeter. It is not possible for the needles of these instruments to follow the rapid fluctuations of the alternating current, and what they indicate is an effective value of current or voltage, *equal to the direct current which would produce the same amount of heat.* It has become the custom to refer to alternating currents on this basis. The relation between the maximum value of the current or voltage of an alternating current, and its effective value is as $\sqrt{2}$ is to 1. So the *effective value* is equal to

$$\textit{maximum value} \times \frac{1}{\sqrt{2}} \text{ or } .707.$$

Then the maximum value equals $\sqrt{2} \times$ effective value, or 1.41.

If an alternating-current voltmeter reads 100 volts, the maximum voltage of each alternation is 100×1.41, or 141 volts. The *average* value is understood to signify the *mathematical average* of the various values during an alternation, and this is found to be .636 times the maximum value; while mathematically, the *effective* value is the result of extracting the square root of the average square of the different values. If the alternations were not shaped like the true sine wave, the above values would have to be modified accordingly. Sine wave current is understood in such calculations.

97. Upon investigating the characteristics of alternating current, it is found that the E. M. F. of a circuit increases

and decreases exactly the same number of times that the current rises and falls in amplitude; but that the increase in E. M. F. is not necessarily instantaneous with the rise in amplitude of current. When the increase in E. M. F. is identical with the increase in amplitude, the current and voltage are said to be *in phase* with each other. Otherwise the current and voltage are *out of phase,* and the degree of this divergence can be indicated by degrees of the circle. For instance, a phase difference of 45 degrees is one in which the lag of one phase behind the other can be shown on a graph of the sine curve as a lag of one-eighth of a cycle, 45 degrees being one-eighth of a *circle.* A lag of any other amount is represented in the same manner. A circuit containing inductance is always somewhat out of phase. It also has a counter emf. which increases and decreases in amplitude in exact proportion to the increase and decrease in E. M. F., or at a phase angle of 180 degrees. With a self-inductive circuit having a current lag of 90 degrees, the instant at which the E. M. F. and the counter emf. have each decreased to zero value is the same instant in which any given alternation in the current has reached its maximum value; and the instant at which the E. M. F. and the counter emf. have reached their maximum is the point at which the current in any alternation has fallen to zero value. The angle of phase displacement, in degrees, is represented by θ, the Greek letter theta.

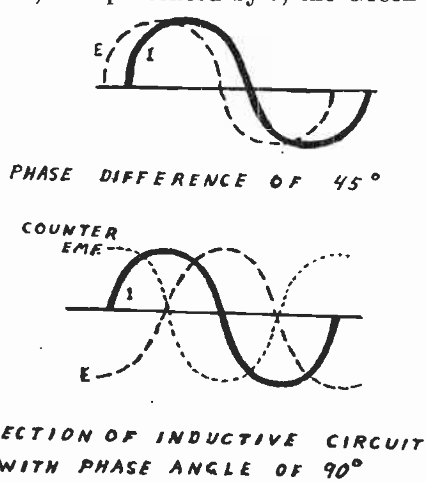


Fig. 61. Alternating Current out of Phase.

98. The *power* of alternating current for doing work is called its *power factor*. *The power factor of an alternating current is the ratio of the actual power to the apparent power.* If a voltmeter and an ammeter are connected in it, the wattmeter will give a reading of power which is something less than the product of the readings of the voltmeter and ammeter. In practical work, the *power factor* is usually determined by finding the ratio of the power indicated by the wattmeter to the product of the voltmeter and ammeter readings. In a direct-current circuit these two readings would be approximately the same, with possibly a small loss allowed for heat. The difference between *apparent power*, $P = E \times I$, and the *true watts* available for use in alternating current is always considerable. A current having a lag of 90 degrees, such as that described in the preceding paragraph, would have so great a difference as to constitute what is sometimes called a "wattless current." The power factor is zero; and while there is current in the circuit, there is no available power for doing work. The phase angle must be something between 1 and 90 degrees. The angle of lag depends on conditions in the external circuit as well as in the windings of the alternator, and as this is difficult to predetermine, commercial alternators are frequently rated in units of *apparent power*, or kilovolt amperes, abbreviated to *Kva.* This is obtained by multiplying the voltage and amperes that can be expected from the machine without injury to it, and does not indicate the actual power available in the external circuit. *A kilovolt-ampere may be defined as the apparent power in an alternating current circuit when the power factor is one and the apparent power is one kilowatt.* (See paragraphs 111 and 112 for formulæ for angle of lag and power factor.)

99. The simple types of alternators described in chapter 9 are single-phase machines, and deliver a single-phase current, such as illustrated in figure 52. Alternating current for power purposes is often supplied *two-phase or three-phase.* This is a different use of the word than that employed in the preceding paragraphs. Figure 61 illustrates an alternating current *out of phase.* Figure 62*a* shows the relation of the various alternations produced by an alternating current *three-phase* system. By placing three sets of armature coils on the single-phase revolving-armature type of alternator and providing it with suitable collector rings

and brushes, we have practically three alternators in one. That is, we have three armatures in one, utilizing the same field poles. As these individual armatures revolve, their coils

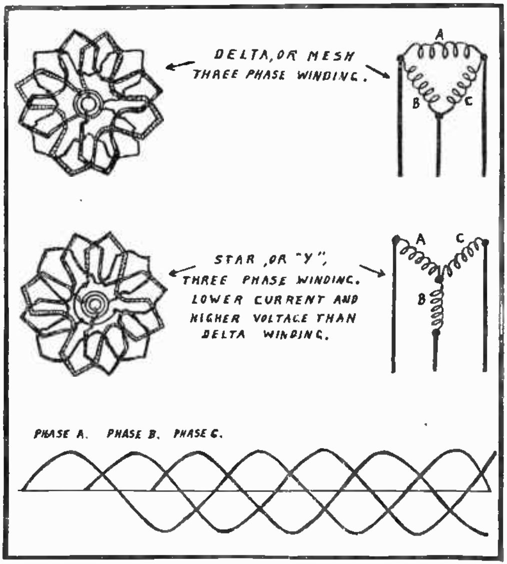


Fig. 62a. Three-Phase Alternating Current, and Generator Windings Used For Three-Phase Systems.

alternately pass through the magnetic flux of the field poles in succession, and each picks up current separately and delivers it to the external circuit. While theoretically there should be three separate circuits and six collector rings, in practice there are generally only three collector rings and three wires, as illustrated in figure 62*a*. When the terminals of these three wires are connected together, it may be considered that each brush in succession delivers a single-phase current to the external circuit by the wire to which that brush is connected, and that this current returns to the generator by way of the other two wires. The *time relation* of the three sets of alternations traversing the three generator windings and the three

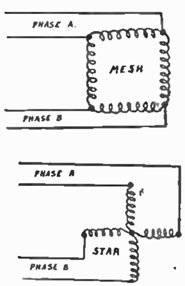


Fig. 62b. Two-phase Alternator Windings.

wires making up the external system is such that the system is said to have a phase displacement of 120 degrees, that is, the separate single-phase currents are 120 degrees apart in relation to each other. Two phases may be produced by alternator windings arranged as in figure 62b. Alternating current systems supplied by generators employing more than one set of armature windings are referred to as polyphase systems. Quoting from *Alternating Current Phenomena*, by Steinmetz: "A three-phase system consisting of three equal emf.'s, displaced by one-third of a period, is a *symmetrical* system. The *quarter-phase* system, consisting of two equal emf.'s, displaced 90 degrees or one-fourth of a period, is an *unsymmetrical* system. The *power* in a single-phase system is *pulsating;* that is, the watt curve of the circuit in a sine wave of double frequency, alternating between maximum value and zero, or a negative maximum value. In a polyphase system the watt curves of the different branches of the system are pulsating also. Their sum, however, or the *total power* of the system may be either constant or pulsating. In the first case, the system is called a *balanced system,* in the latter case an unbalanced system. The three-phase system and the quarter-phase system, with *equal load* on the different branches, are balanced systems; with *unequal* distribution of load between the individual branches, both systems become unbalanced. The different branches of a polyphase system may be either independent from each other, that is, without electrical interconnection, or they may be interlinked with each other. In the first case the polyphase system is called an independent system, in the latter case an interlinked system. The *power* of a polyphase system is the *sum* of the powers of all the individual branches; and the sum of the wattmeter readings of all the branch circuits thus gives the *total power.* The three-phase system requires three-fourths as much copper to transmit a given power as the single-phase system of the same potential."

100. The voltage across the outside wires of a three-wire circuit, using alternating current, is not always twice the voltage of one side of the circuit, as is invariably the rule with direct current. (Figure 28.) It may be, or may not, according to the effect of the phases and the connections to the source of power. Alternating current from city power lines must be rectified, or have the alternations in one direc-

tion stopped, producing a one-way pulsating current, for some purposes, such as charging storage batteries and electroplating. With one or two exceptions, d. c. machinery cannot be operated on it. It is necessary to use heavier insulations for it than for d. c.; and it is considerably more dangerous to handle. However, the fact that it can be stepped up or stepped down through a transformer offsets all the disadvantages mentioned, for certain purposes.

The filament of a lamp lighted on alternating current can be seen to vibrate if a horseshoe magnet is placed near it. Direct current causes the filament to be attracted steadily.

101. Direct current is believed to completely penetrate conductors, and to cause that phenomenon which we call a "flow of current" *throughout the material* composing the conductor. Alternating current appears to act more on or near the surface of conductors. This is called the *"skin effect."* It probably is not confined strictly to the surface, but does not penetrate to the center of the conductor. This skin effect is more pronounced the higher the frequency. It appears that it takes a fraction of time for the penetrating effect to take place, and that the faster the change of direction of the current the less time is there for the action to reach the inner portion of the conductor. For this reason flat metal "ribbons," or conductors composed of many strands of fine wires, are better conductors of alternating current than solid round wires. It is believed that stranded wire conductors are more efficient when the separate wires are protected from each other with some appropriate insulation, such as a coating of enamel.

TABLE OF LETTER SYMBOLS USED IN ALTERNATING CURRENT CALCULATIONS

C = Capacitance.	X_L = Inductive reactance.
F = Frequency.	X_c = Capacity reactance.
G = Conductance.	Y = Admittance.
L = Inductance in henries.	Z = Impedence.
N = Number cycles per second (same as frequency).	$\pi = 3.1416$.
	θ = Angle of lag.
S = Susceptance.	Φ = Magnetic flux.
X = Reactance.	

CHAPTER 11

Inductance

Magnetic Lines of Force—Ampere Turns—Definition of a Henry—Lenz's Law—Self Induction—Effects of Inductance on Current and Frequency—Counter Emf.—Impedence—Ohm's Law for A. c.—Inductive Reactance—Conductance, Susceptance and Admittance—Angle of Lag—Table of Tangents and Cosines—A. c. Problems

102. In Chapter 3 we established the fact that a magnetic flux always exists around a conductor charged with direct current: that the lines of force composing this flux *move in a counter-clockwise direction around the wire* as the movement of electrons takes place from negative to positive; and that when a portion of the charged wire is wound into a solenoid, the lines of force unite from loop to loop and give the solenoid all of the properties of a magnet. If we insert a bar of iron, we greatly increase the magnetic field of the solenoid. With a fixed value of current we can increase the magnetism of the solenoid by increasing the number of turns of wire. Or, with a fixed number of turns of wire, we can increase the magnetism by increasing the value of the current. The number of amperes of current multiplied by the number of turns of wire gives a product which is called "ampere turns." The strength of the magnetic field, ignoring the iron core, or leaving it out of the solenoid temporarily, is then found to be dependent upon the number of "ampere turns," or the amount of direct current and the number of loops of wire. The increased magnetism due to adding the iron core, depends upon the ampere turns and the permeability of the iron. If the core has reached the saturation point, where its molecules have all been internally arranged lengthwise, as in figure 11, and is capable of no further magnetism, increasing the ampere turns of the solenoid will increase the magnetic flux by simply the additional effect of that one turn.

The intensity of a magnetic field around a single loop of wire charged with direct current can be computed, following the principle that it has a line integral* around the current equal to

$$I \times \frac{4\pi}{10}$$

The magnitude of the field through a solenoid would then be

$$\frac{4\pi}{10} \times \frac{NI}{l}$$

with N representing the number of loops, I the current in amperes and l the length in centimeters.

103. If a solenoid be charged with alternating current, instead of direct current, the movement of the linked magnetic lines of force, as the current reverses its direction, induces a back emf. through the coil. This is called self induction, or self inductance and, according to Lenz's law, the induced emf. is in such a direction as to oppose the flow of the current producing it. (A stored-up back emf. in a coil may be illustrated by connecting it across the terminals of a dry cell and suddenly disconnecting one end of the wire. The spark will be much brighter than when a straight wire is used. This is on account of the collapse of the magnetic field stored up in the coil by the back emf. At this instant the induced E. M. F. follows the direction of the current, momentarily increasing its volume.)

The emf. induced in the coil is in proportion to the rate of change of the magnetic flux, which in turn depends upon the rate at which the current reverses its direction through the wire. Hence, with n representing the number of turns of wire, φ the magnitude of the flux, and t time,

$$\text{Emf.} = \frac{n\varphi}{t}$$

104. *Inductance may be defined as the property in a circuit for storing up electromagnetism.* Its unit is the *henry,* named in honor of Joseph Henry, first secretary of the Smithsonian Institution, Washington, D. C., who made extensive experiments in magnetism and electromagnetism. *One henry is that amount of self-induced magnetism*

*"The line integral of a quantity along any line or path is the sum of the products of the length of each element of the path by the value of the quantity along that element." *Circular of the Bureau of Standards No. 74.*

which causes an induced emf. of one volt when the current in the circuit varies at the rate of one ampere per second. It is also sometimes defined as the energy which is induced by the cutting of one hundred million lines of force per second. Inductance is a property of alternating or pulsating current only. The symbol used to represent inductance in henries is L. For small amounts of inductance, the units microhenry, one-millionth of a henry, and millihenry, one-thousandth of a henry, are used. Occasionally the centimeter of inductance is used, being one-billionth of a henry.

One m. h. = one millihenry = .001 henry.
One μ h. = one microhenry = .000001 henry.
One cm. h. = one-thousandth of a microhenry = .000000001 henry.

The inductance in a circuit, or through a coil of wire, is, in effect, the suspended magnetic flux produced by the changing current. This, of course, depends somewhat upon the size and shape of the circuit and the coils included. The following, with φ representing flux, I current in amperes, and L inductance in henries, is the simplest fundamental equation dealing with inductance and flux:

$$L = \frac{\varphi}{I}$$

105. When direct current is passed through a solenoid, there is one movement around the solenoid, in establishing the magnetic field of that coil, and this remains approximately the same. The magnetic field of fixed direction does not retard the flow of current through the coil or the rest of the circuit. A lamp or an ammeter connected in circuit with the coil when it is energized with direct current, and indicating a certain flow of current, will, if the coil be charged with alternating current, indicate that much *less current flows* when *inductance* is present. The *magnetism* stored about the coil by the movement of the current in one direction *clings,* and *opposes* the newly formed magnetic lines of force produced by the current turning in the opposite direction, *actually decreasing the flow of the current.* By the opposing effect against the reversal of the magnetic polarity of the solenoid, each alternation is also opposed, so that it takes a fraction of time longer for it to accomplish its half cycle of rising amplitude, and the *frequency* of the current may be reduced accordingly, if it is free to vibrate

at its own frequency, or otherwise less current can flow on account of the circuit being out of resonance with its source of supply.

It may be seen how the above facts must be taken into consideration in the design of all circuits for the use of alternating current; and how under certain conditions inductance may be made to serve a definite purpose. One of these is what is generally called a "choke coil." This is simply an iron-cored electromagnet used in an alternating-current circuit for the purpose of controlling, within limitations, the flow of current. A coil of high-resistance wire passes all of the current that is normally in the circuit, but consumes a portion of it in heat. Thus that current which is held back by a controlling resistance is wasted. An inductance used for this purpose, does not waste the current in heat, but acts upon it somewhat in the manner of a brake.

106. The *back electromotive force* due to inductance in a circuit is called *reactance*—the current reacting upon itself. There is some reactance throughout an alternating-current circuit, but this is much more pronounced in a solenoid, where the magnetic lines of force are united. The reactance in circuits having inductance is responsible for the *lag and lead effect,* or that condition of the current illustrated in figure 61, where the current is shown *out of phase.*

107. It is possible to neutralize the effect of inductive reactance by winding a coil in two sections in opposite directions. Their magnetic fields then oppose each other, and the reactance effect upon the current is minimized. An iron core inserted in a solenoid wound in this manner would not increase its magnetism to any extent, and would not exhibit the usual polarity of an electromagnet. Coils are wound in this manner for testing purposes principally.

108. It is necessary to make a modification in Ohm's law for calculations concerning current having reactance. The simple equation of Ohm's law which states that the current equals the E. M. F. divided by the resistance, or $I = \frac{E}{R}$, is not true of an inductive circuit, because of the influence of the back emf, which impedes the flow of current. Therefore, we have *Ohm's law for alternating current.* The unit for

reactance is the ohm, the same as the unit of resistance. While the cause of the opposition is very different, the total result is the same, viz., that of retarding the flow of the current. The total combined opposition is called impedence. *Impedence may be defined as the total opposition to the flow of current offered by the metallic resistance and the reactance combined.* It is symbolized by the letter Z. Impedence of high-frequency circuits generally includes capacity reactance, which is treated in chapter 18. Considering circuits having reactance due simply to inductance, it would seem that the impedence might be equal to the sum of the resistance and the reactance. However, on account of the current in an inductive circuit being out of phase, this is not exactly accurate; and the true equation representing the effective opposition, or total impedence, is

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

with X_L representing inductive reactance.

This relation in electrical values is the same thing mathematically as the length of the hypothenuse of a triangle. If you draw a right angle triangle having a base, or abscissa, 4 inches long, and a vertical side, or ordinate, 3 inches long, the hypothenuse will not be 3 + 4, or 7 inches long. It will be 5 inches long, and 5 is the square root of $4^2 + 3^2$. So, impedence is not equal to resistance plus reactance; but to the *square root of the sum of the squares of each.*

$$\text{Then,} \quad I = \frac{E}{\sqrt{R^2 + X_L^2}}.$$

$$X_L = \sqrt{Z^2 - R^2}, \text{ and } R = \sqrt{Z^2 - X_L^2}$$

X_L is also calculated by multiplying frequency, F, by inductance in henries, L, and the product by $2 \times \pi$ $(2\pi FL)$.

The inductance may be found by the following formula:

$$L = \frac{X_L}{2\pi F}, \text{ and } X_L = 2\pi F L$$

Upon considering the relation of π to a circle, the reason for the frequent use of 2π in alternating-current formulæ can be understood. It is a mathematical equation representing the *time period* required for the completion of *one cycle* of harmonic motion.

($\pi = 3.1416$. The circumference of a circle is equal to the diameter, or twice the radius, multiplied by 3.1416. This is usually written $2r\pi$.)

109. *The total E. M. F. in a circuit having inductance* is equal to the E. M. F. required to overcome the metallic resistance, and the E. M. F. necessary to overcome the reactance, or,

$$E = \sqrt{(I \times R)^2 + (I \times X)^2}$$

The relation between the resistance, reactance and impedence, can be seen when they are represented by a triangle,

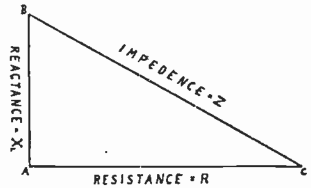


Fig. 63. Relation Between Resistance, Reactance and Impedence

as in figure 63, where the distance between B and C is equal to the square root of the sum of the squares of AB and AC. For instance, if in the equation represented by figure 63, the metallic resistance of the circuit is 4 ohms, and the reactance due to inductance is 3 ohms, we prove the total impedence to be 5 ohms, by substituting in the formula,

$$Z = \sqrt{R^2 + X^2} = \sqrt{4^2 + 3^2} = \sqrt{16 + 9} = \sqrt{25} = 5 \text{ ohms.}$$

The total impressed E. M. F. is also illustrated by a triangle, as in figure 64. After the total values of the current

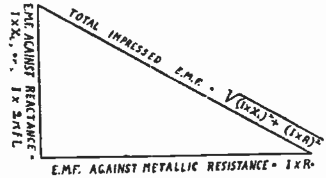


Fig. 64. Representation of Relation of Total E. M. F. to Resistance and Reactance.

and voltage and impedence have been determined by the above rules, Ohm's law may be stated simply, as follows:

$$E = I \times Z, \quad I = \frac{E}{Z}, \quad \text{and} \quad Z = \frac{E}{I}.$$

110. Two or more inductance coils connected in parallel will be found to offer a joint impedence. In paragraph 52 a rule was given for determining the conductance of parallel *resistance* coils by the reciprocal method, proving the direct current conductance to be the reciprocal of the resistance. With alternating current, with coils of either high or low metallic resistance, the total impedence effect is the result of various factors. With an inductive circuit we have *effective conductance,* and also *susceptance, which is the opposite of reactance.*

$$\text{Effective Conductance} = \frac{R}{R^2 + X^2}.$$

$$\text{Susceptance} = \frac{X}{R^2 + X^2}$$

A non-inductive device, such as a lamp, when placed in an alternating-current circuit, will have a conductance equal to the reciprocal of its resistance; and as it has no reactance, it has zero susceptance.

The total *impedence* also has a reciprocal, which is called *admittance:*

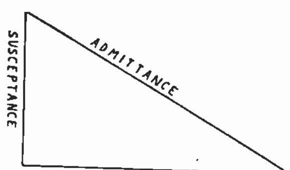


Fig. 65. Diagram of Relation Between Effective Conductance, Susceptance and Admittance.

Where G represents conductance, S susceptance, and Y admittance,

$Y = \sqrt{G^2 + S^2}$. This is the complete reciprocal of

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

CIRCULAR TRIGONOMETRIC FUNCTIONS

NATURAL TANGENTS AND COSINES

Deg. θ	tan.	cos.	Deg. θ	tan.	cos.	Deg. θ	tan.	cos.
1	.017	1.000	41	.869	.755	81	6.314	.156
2	.035	.999	42	.900	.743	82	7.115	.139
3	.052	.999	43	.933	.731	83	8.144	.122
4	.070	.998	44	.966	.719	84	9.514	.105
5	.087	.996	45	1.000	.707	85	11.43	.087
6	.105	.995	46	1.036	.695	86	14.30	.069
7	.123	.993	47	1.072	.682	87	19.08	.052
8	.141	.990	48	1.111	.669	88	28.64	.035
9	.158	.988	49	1.150	.656	89	57.29	.018
10	.176	.985	50	1.192	.643	90	*	0.000
11	.194	.982	51	1.235	.629			
12	.213	.978	52	1.280	.616			
13	.231	.974	53	1.327	.602			
14	.249	.970	54	1.376	.588			
15	.268	.966	55	1.428	.574			
16	.287	.961	56	1.483	.559			
17	.306	.956	57	1.540	.545			
18	.325	.951	58	1.600	.530			
19	.344	.946	59	1.664	.515			
20	.364	.940	60	1.732	.500			
21	.384	.934	61	1.804	.485			
22	.404	.927	62	1.881	.470			
23	.424	.921	63	1.963	.454			
24	.445	.914	64	2.050	.438			
25	.466	.906	65	2.145	.423			
26	.488	.899	66	2.246	.407			
27	.510	.891	67	2.356	.391			
28	.532	.883	68	2.475	.375			
29	.554	.875	69	2.605	.358			
30	.577	.866	70	2.748	.342			
31	.601	.857	71	2.904	.326			
32	.625	.848	72	3.078	.309			
33	.649	.839	73	3.271	.292			
34	.675	.829	74	3.487	.276			
35	.700	.819	75	3.732	.259			
36	.727	.809	76	4.011	.242			
37	.754	.799	77	4.332	.225			
38	.781	.788	78	4.705	.208			
39	.810	.777	79	5.145	.191			
40	.839	.766	80	5.671	.174			

*—infinite.

When *impedences* are connected in *parallel,* the joint impedence is determined by first finding its reciprocal, or the *joint admittance,* and then dividing one by this number.

$$\text{Total joint impedence} = \frac{1}{\sqrt{(G_1+G_2+G_3)^2+(S_1+S_2+S_3)^2}}$$

For instance, with the effective conductance and the susceptance of each impedence having the values given in the illustration, figure 66,

$$G_1 = \frac{R_1}{R^2+X^2} = \frac{4}{16+9} = \frac{4}{25} = .16$$

$$S_1 = \frac{X_1}{R^2+X^2} = \frac{3}{16+9} = \frac{3}{25} = .12$$

$$G_2 = \frac{R_2}{R^2+X^2} = \frac{4}{16+64} = \frac{4}{80} = .05$$

$$S_2 = \frac{X_2}{R^2+X^2} = \frac{8}{16+64} = \frac{8}{80} = .10$$

$$G_3 = \frac{R_3}{R^2+X^2} = \frac{2}{4+36} = \frac{2}{40} = .05$$

$$S_3 = \frac{X_3}{R^2+X^2} = \frac{6}{4+36} = \frac{6}{40} = .15$$

$$Z = \frac{1}{Y} = \frac{1}{\sqrt{(G_1+G_2+G_3)^2+(S_1+S_2+S_3)^2}} =$$

$$\frac{1}{\sqrt{(.16+.05+.05)^2+(.12+.10+.15)^2}} =$$

$$\frac{1}{\sqrt{.26^2+.37^2}} = \frac{1}{\sqrt{.2045}} = \frac{1}{.452} = 2.2 \textit{ ohms joint impedence.}$$

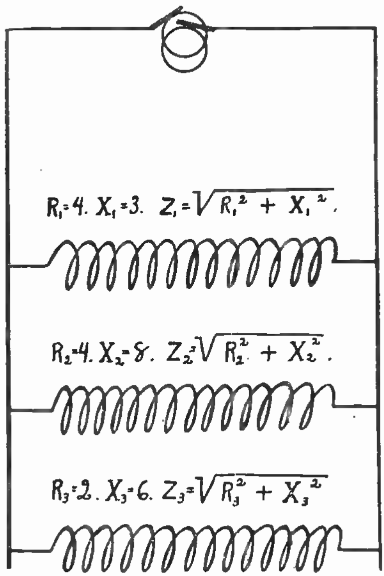


Fig. 66. Impedences in Parallel.

The total impedence of the same three coils connected in series would be as follows:

$$Z = \sqrt{(R_1 + R_2 + R_3)^2 + (X_1 + X_2 + X_3)^2} =$$

$$\sqrt{(4 + 4 + 2)^2 + (3 + 8 + 6)^2} =$$

$\sqrt{10^2 + 17^2} = \sqrt{100 + 289} = \sqrt{389} = 19.73$ *ohms impedence.*

111. Returning to the subject of the angle of lag (See paragraph 98), we find that the *tangent* of the *angle of lag* is equal to the reactance divided by the resistance, or,

tangent of θ, generally written tan θ, $= \dfrac{2\pi f L}{R}$, or $\dfrac{X_L}{R}$.

A tangent is a straight line which touches the circumference of a circle but does not intersect it.

(The ratios of any two sides of right angle triangles are named. The most useful of these are the sine, cosine, and tangent. With the sides of a triangle named x, y, and a, as in figure 67, the ratio of

$$\frac{y}{a} = \text{sine of } \theta, \text{ or } \sin \theta$$

$$\frac{x}{a} = \text{cosine of } \theta, \text{ or } \cos \theta$$

$$\frac{y}{x} = \text{tangent of } \theta, \text{ or } \tan \theta$$

See trigonometry for further information on the subject.)

With a reactance of 5 ohms and a resistance of 6 ohms,

$$\tan \theta = \frac{5}{6} = .83 +.$$

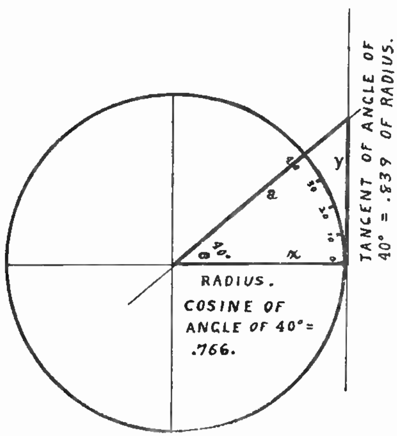


Fig. 67. Tangent and Cosine of θ of 40°.

This is the *tangent* of the angle, and *not the angle in degrees.* It is then necessary, in order to determine the angle of lag from this equation, to know the angle of which the tangent would be .83+. The ratio of the tangent to the angle can be worked out for each problem arising, but tables of these numbers have been compiled for convenience. From the accompanying table it can be seen that .839 is the tangent of 40°, thus the current in this circuit lags 40°.

112. The *power* of an alternating current may be calculated, when the angle of phase displacement has been determined, as follows:

$$\text{Power} = E \times I \times \cos\theta$$

$$\text{The cosine of the angle of lag} = \frac{\text{Resistance}}{\text{Impedence}}, \text{ or } \cos\theta = \frac{R}{Z}$$

and $R = Z \times \cos\theta$. The $\cos\theta$ is also equal to $\dfrac{P}{E \times I}$

The $\cos\theta$ of an alternating current is generally called its *power factor*. This number is always something between 1 and zero.

113. In the high-frequency circuits of the various types of radio apparatus used for both transmitting and receiving, *inductance coils* having variable connections are used. Varying the amount of inductance used in the circuit varies the frequency; and this is exactly the effect which is sought. It makes it possible to *control* the frequency very accurately, and to place a piece of apparatus "in tune" with another piece of apparatus, which may be located at a great distance.

Alternating-Current Problems.

1. What is the impedence of a circuit in which 9 amperes of alternating current are flowing at a pressure of 220 volts?

Answer. 24.4 ohms.

2. A circuit, supplied with current from a 60-cycle alternator at an E. M. F. of 110 volts, has a resistance of 25 ohms and an inductive reactance of 8 ohms.

(*a*) What is the impedence of the circuit?

Answer. 26.2 ohms.

(b) What is the inductance in henries?

Answer. .021 henries.

(c) How many amperes of current are flowing?

Answer. 4.2 amperes.

3. What is the angle of lag in an alternating current having an inductive reactance of 8 ohms, when the resistance of the circuit is 5 ohms?

Answer. 58 degrees.

4. What is the percentage of the power factor of an alternating current circuit in which the impedence is 250 ohms and the resistance 125 ohms?

Answer. 50 per cent.

5. An alternating-current power line delivers current of 15 amperes at a pressure of 500 volts. The angle of lag is 45°.

(a) What is the apparent power?

Answer. 7.5 K. W.

(b) What is the true power?

Answer. 5.3 K. W.

6. Three incandescent lamps and three choke coils are connected in series in an A. C. circuit. The lamps have each a resistance of 200 ohms. The choke coils have each a resistance of 10 ohms, and an inductive reactance of 35 ohms. What is the total impedence of the group of lamps and choke coils?

Answer. 638.68 ohms.

7. The same devices referred to in problem 6 are connected in parallel. What is the joint impedence?

Answer. 11.36 ohms.

8. What is the maximum value of the alternations of a current flowing through a circuit in which the ammeter gives a reading of 18 amperes?

Answer. 25.38 amperes.

CHAPTER 12

Generators and Power Lines

Direct-Current Generator, Shunt, Series and Compound—Function of Commutator—Rules for Potential Difference, Volt Drop, etc., of Generator—Field Rheostat—D. C. Armature Windings—Compensating Poles—Commutating Plane—Heel and Toe Voltage—Marine Generator—Generator Efficiency—Three-Wire D. C. Power Lines—Power-Line Alternators with Self-Contained D. C. Field Supplies—Circuit-Breaker—Table of Current-Carrying Capacity of Insulated Wire.

114. Strictly speaking, any machine for generating electrical energy is a generator, whether it produces direct or alternating current. There is a tendency, especially among radio electricians, to distinguish between the two by referring to the generator of direct current as a dynamo and to the generator of alternating current as an alternator. The construction of the direct-current generator is similar to that of the alternator, excepting for the manner of winding the armature and connecting it to the external circuit. It may be revolved by any external source of power available; and the energy supplied to the field may be residual magnetism, or it may be supplied from the armature of the machine, or from some external source, such as storage batteries or another direct-current generator.

115. If figure 68 is compared with figure 42, it will be seen that in this machine the collector rings have been replaced by two separate segments, or halves of one ring, to which the opposite ends of the single-loop armature have been attached. While in the alternator each brush makes continuous contact to the same ring as the shaft revolves, in the direct-current generator the brushes make contact with first one segment and then with the other as the shaft is revolved. The current reverses its direction within the coil as in the alternator, and as was explained in paragraph 85; but *the two separate sections, as thy revolve, slide first under one brush and then under the other,* and *reverse the connection of the coil to the external circuit.* This is called commutation, and the two segments are known as a commutator. *The function of a commutator on a d. c. generator is to reverse or commute the alternating current induced into the armature at the proper instant in each cycle so that the current flowing in the external circuit will be always in the same direction.* The *alternations* take place in the loop of wire, but the loop is *turned over,* making contact with the brushes at opposite

terminals of the armature for every other alternation; and the current flowing in the *external circuit* is therefore flowing in *one direction*. This produces a current which is decidedly pulsating in character. In practical machines this is overcome by using armatures consisting of many loops attached to a large number of commutator segments.

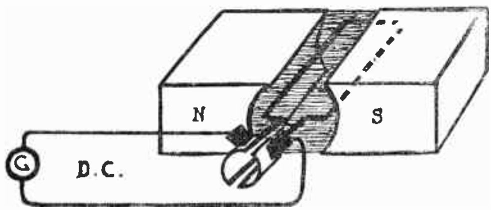


Fig. 68. Simple Direct-Current Generator.

116. It will be noticed that the machine illustrated in figure 68 is of the magneto type. That is, the only source of energy is the residual magnetism in the field-pole magnets. Obviously this is a self-exciting machine, the only external power being supplied to it being the mechanical means used to turn the shaft on which the armature is mounted. If a coil of wire be wound around the field poles, and has its terminals connected to the brushes which deliver current to the external circuit, a portion of the current will pass through this coil, making *electromagnets* of the field poles, thus greatly increasing the strength of the magnetic field surrounding them, and increasing the power supplied to the external circuit. Field windings connected across the brushes are called shunt windings; and the generator is known as a shunt-wound generator.

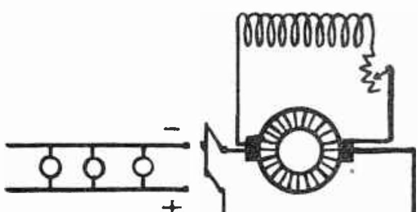


Fig. 69. Diagram of Self-Excited Shunt-Field Dynamo Supplying Direct Current to External Lamp Circuit.

The shunt field winding consists of a great many turns of fine wire. The resistance is high, and the amount of current in the winding small. By adding a resistance with a variable connection, we can regulate the current flowing through the field winding by increasing or decreasing the resistance. The device used for this purpose is called a rheostat. The *resistance of the rheostat is added to or subtracted from the resistance of the field winding. When increased, less current will flow through the winding, the magnetic flux will be decreased accordingly, and there will be less energy picked up. When the resistance is decreased, more current will flow, and the voltage of the ouput will be increased.* The potential difference at the brushes is found to fall off when an external load is placed on the generator. For instance, if a number of lamps, or a motor, be connected to the brushes of a d. c. generator, they will draw current from it which can not flow when the external circuit is open. This means that more current is flowing through the armature, with the result that the pressure is lowered. Then, the pressure in the armature and at the brushes being lowered, less current flows through the field winding, and less energy is picked up by the armature. The percentage of this change of voltage is known as the regulation percentage and is determined as follows:

$$\frac{\text{no-load voltage} - \text{full-load voltage}}{\text{full-load voltage}} = \text{percentage of voltage regulation}$$

While the current varies according to the load, the voltage of this type of machine remains fairly constant, on load, as compared to the series generator.

The rule for the relation between no-load voltage and full-load voltage applies also to alternators, but the current through the separately-excited d. c. field winding is not affected in the same way as the current through the shunt field of a d. c. generator taking its field current from its own armature.

(1) *The current flowing through the armature of a self-excited shunt-wound d. c. generator is equal to the sum of the current flowing in the external circuit and that flowing through the shunt field winding.*

(2) *The current flowing in the shunt field winding of a self-excited d. c. generator is determined by dividing the potential difference at the brushes by the field resistance.*

(3) *A series field winding, being in series with the line, has a volt drop which is calculated in the same manner as the line drop. Hence, at the terminal connections to a series generator, the voltage is equal to the potential difference at the brushes minus the series field drop.*

(4) *The potential difference at the brushes of a generator is always equal to the voltage at the end of the line, or at any point along the line, plus the line drop in volts between the brushes and that point.*

(5) *The line drop in volts is equal to the product of the current flowing through the line and the resistance of the line.*

(6) *The total E. M. F. generated is equal to the potential difference at the brushes, plus the volts dropped in the armature.*

(7) *The volts dropped in the armature are equal to the product of the current flowing through the armature and the armature resistance.*

(8) *Watts lost in the armature are equal to the product of the volts dropped in the armature and the armature current. Watts lost are also equal to* $I^2 \times r$.

117. When the field windings are connected in series with the brushes and the circuit being supplied with current, as in figure 70, we have a *series self-excited direct-current generator.* In this case the field winding is composed of a comparatively few turns of heavy wire. If the rheostat is omitted, the full supply of current passes directly through the series field winding, hence the heavy wire is necessary. When a field rheostat is used it is connected in shunt around

the series field winding. It will be noticed that the *rheostat* is connected *in series with a shunt field,* and *in shunt with a series field.* While the ampere turns may have about the same value in this machine as in the shunt machine, they are the result of a large amount of current with a few turns of heavy wire, as compared to the larger number of turns of fine wire carrying a smaller amount of current in the shunt field. The heavy series winding, being directly in series with the brushes and the armature winding, is directly affected by every change in the external load. When any device with high resistance is connected in the external circuit, this resistance is placed in series with the series field winding, and the generator voltage is immediately lowered. If the external resistance is too high, the generator may not "build up" at all; and under any circumstances it cannot "build up" until the external circuit is closed. The type of rheostat shown in figure 70 is constructed to automatically bal-

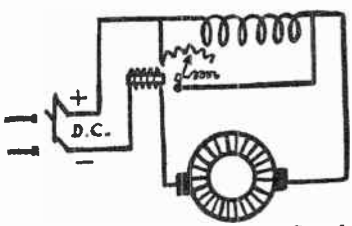


Fig. 70. Diagram of Self-Excited Series Dynamo Supplying Direct Current to an External Circuit.

ance the resistance of the external circuit and the resistance of the series field winding. An iron bar, acting as the core of an electromagnet, automatically attracts or releases the moving arm which makes contact with the field rheostat. When the resistance in the external circuit is lowered, more current will flow through the solenoid and the core will draw the arm across the contact points and cut out resistance in the shunt, thus taking more current away from the field, and balancing the drop in load. When a load having high resistance is placed on the external circuit there is less current in the solenoid, and the arm is released, and the rheostat resistance is cut into the circuit with the *shunt,* allowing more current in the field winding. This arrangement is not always employed with series generators. If some type of regulator is not used, both the current and the voltage will rise and fall with every change in the load. When a voltage regulator is used, the current supplied is fairly constant. The series generator is known as a *constant-current* machine, as compared to the shunt generator, which maintains a more constant voltage than the series machine. A voltage regulator somewhat similar to that described above is sometimes used in connection with a shunt generator also.

118. With a *compound winding,* consisting of both the shunt and series field, we have the advantage of both machines combined in one, and there is an automatic balance

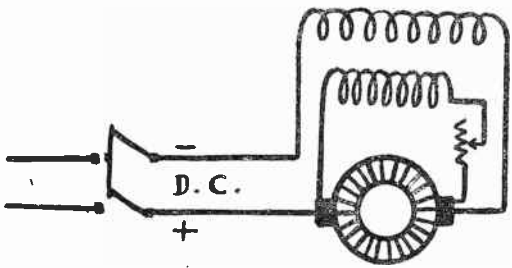


Fig. 71. Diagram of Compound Generator, with Short Shunt.

between the two fields, which keeps the output more nearly constant than with either of the single windings alone. When a load is placed on the generator, the extra current flowing through the series field windings adds to the magnetic lines of force through which the armature revolves, and *counteracts* the decrease in current in the shunt winding. This results in approximately constant voltage, or in a high regulation percentage. There is not the fall in potential across the brushes when a load is applied, as in the simple shunt generator. In compound machines, the shunt field winding may be connected as in figure 71, when it is known as a short shunt, or it may be connected as in figure 72, when

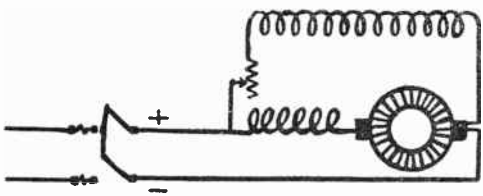


Fig. 72. Compound d. c. Generator with Long Shunt.

it is known as a long shunt. The long shunt bridges the series field winding. By using more turns in the series field than is necessary to maintain a constant potential, the voltage can be made to *rise* as the load is increased, thus making up for line loss and delivering a constant voltage at the terminals of the line. A generator thus wound is said to be *over-compounded. The volts dropped in the series field winding is the product of its resistance and the current flowing through it.*

119. Self-excited d. c. generators are used extensively. However, in some cases it is more desirable to energize the field windings from an external source. Figure 73 illustrates this method. In such a machine the field winding is not affected to any extent by the external load; and the percentage of regulation is due solely to the variation of current through the armature.

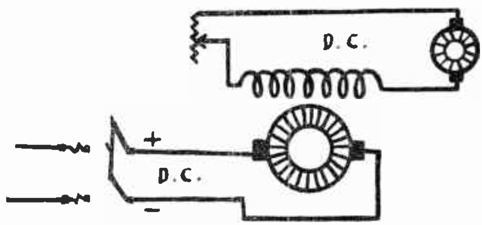


Fig. 73. Separately-Excited D. C. Generator.

120. High-powered d. c. generators are composed of a large number of armature loops having comparatively small inductance, and usually have several pairs of field poles. The two-pole machines are seldom used at present, excepting for the small magnetos, and some exceedingly large machines with powerful, heavy, permanent magnets, and which are driven by water power or steam at an extremely

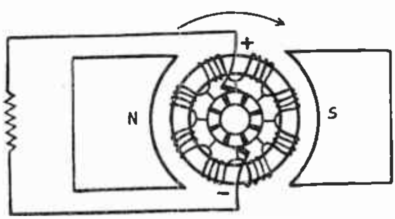


Fig. 74. Eight-Coil Ring-Wound Armature.

high speed. For ordinary purposes, and with an ordinary amount of propelling power, it is found advantageous to obtain the required voltage at slower speed, and with more field poles. There must always be as many pairs of brushes as there are pairs of field poles, the positive brushes being all connected to the positive side of the external circuit, and the negative brushes to the other. The reason for this may be seen by considering the direction of the current through the armature coils. In figure 74 is illustrated an eight-coil Gramme ring-wound generator armature. The ring-wound armature is about obsolete for practical dynamos, but it serves to illustrate the direction of current, and is somewhat simpler to follow than the later types. In this armature, when the external circuit is closed, current is induced into each half of the armature that lies to the left or right of the brushes, as the armature revolves. As each loop passes the negative brush, and the one opposite to it on the ring passes the positive brush, the direction of current in each half is reversed. This process is the commutation previously referred to. Each time that the current reverses its direction in the armature winding we have a reactance voltage set up against the flow of current in the coil, as is invariably the case with self-inductive circuits, and it is necessary that an E. M. F. of sufficient strength to overcome this be picked up by the armature in order to continue operation. In this simple eight-coil armature two-field-pole machine, *the current flows downward on each half of the armature,* and to the external circuit by way of the negative brush. This is because one-half is cutting the lines of force *upwards,* and the other cutting them *downwards.* If we increase the number of alternate field poles, we must increase

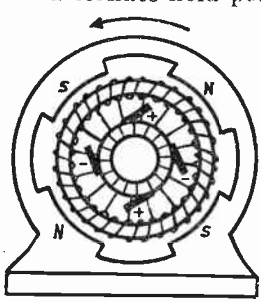


Fig. 75. Ring-Wound Armature Provided with Four Brushes for Delivering Energy induced from Four Field Poles.

our connections to the external circuit accordingly. This type of armature winding is known as a closed-coil winding. It is a continuous circuit, although the portion directly parallel with the lines of force of the inducing field are picking up the most E. M. F. When the loops are connected separately to opposite pairs of commutator segments we have an open-coil armature. This is not used as much as formerly.

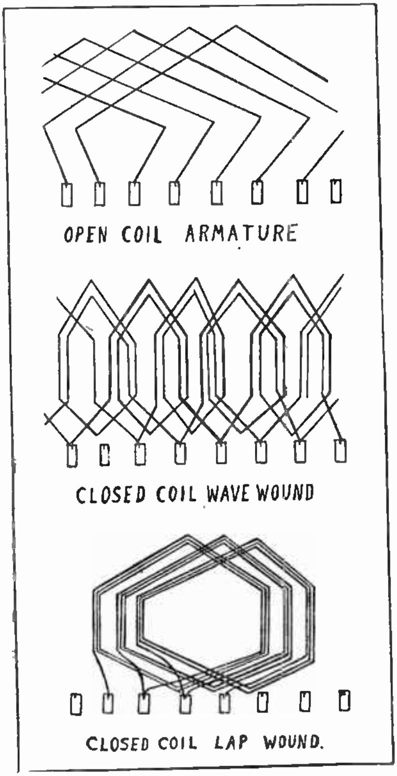


Fig. 76. Methods of Connecting Open-Coil and Closed-Coil Armature Windings to Commutator Segments.

121. In modern d. c. generators, or dynamos, the armature is usually wound in the closed-loop method over a laminated drum, consisting of many sheets of thin steel, the surfaces of which have been shellacked. In the larger machines the armature loops are generally formed, baked

and pressed into the slots in the core. The core is made hollow to reduce weight and heating. The supporting framework inside of the hollow armature core is called a spider. With the ring type of armature only the wires composing the outside of the armature are actually cutting through the lines of force. With the "formed" windings, which are pressed into the slots in the surface of the core, all of the wire is on the surface and hence all are cutting the magnetic

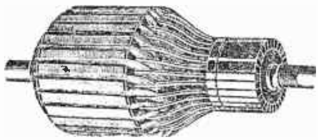


Fig. 77. Laminated Drum-Wound Armature.

flux, and the efficiency of the machine is increased. As the iron core of the armature is a conductor of current as well as magnetizable material, there is a certain amount of current induced into this as it revolves, and what are known as *eddy currents* are produced in the core. This is wasteful of the energy supplied for inducing current for the external circuit. This current also produces heat. These two effects, with the addition of magnetic *hysteresis* constitute the causes of *internal losses in dynamos.* They are partially counteracted by the modern methods of laminating.

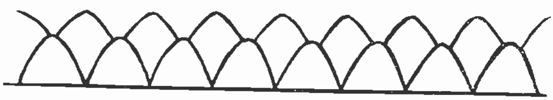


Fig. 78. Overlapping Pulsations of Current from Multicoil d. c. Armature.

122. The commutator and brushes making connection with the external circuit must be in proper relation to each other, or there will be sparking. The commutator consists of segments of hard-drawn copper, held in place on the shaft by the key-like manner of their cut. The segments are insulated from each other by sheets of mica, and the entire commutator insulated from the shaft. If one of the segments or a piece of mica becomes loose and rises a little above the others, every time that this raised piece passes under a brush there will be a severe spark. The commutator also wears in grooves, which must be smoothed down by

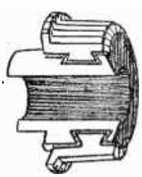


Fig. 79. Cross-Section of Commutator.

pressing a piece of fine sandpaper against it while running, or if badly worn by turning it down in a lathe. The brushes consist of bars of carbon held in place by holders equipped with springs which press against the carbons and keep them tight against the commutator, gradually pushing them farther into the holder as they wear down. If the brush holders are not properly designed, or properly adjusted,

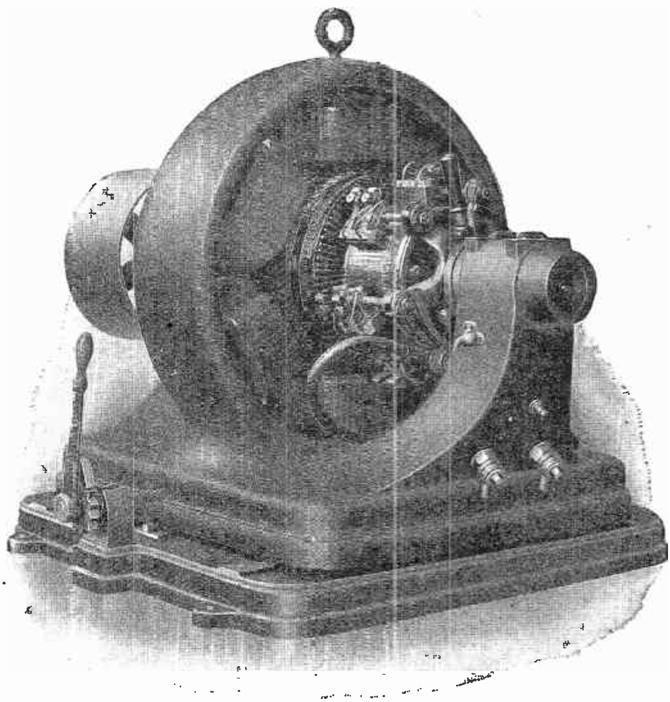


Fig. 80. Western Electric Type ML Direct-Current Generator, without Compensating Poles.

they may vibrate, which will cause sparking. The brushes are mounted on a "rocker arm," an adjustable portion of the iron framework, which permits a "rocking" or swinging around of the brushes and the arm, in order to adjust the brushes to the best position on the commutator, or to the commutating plane. If the brushes are out of this plane this will also cause severe sparking.

123. *The commutating plane is that point of adjustment where the brushes exchange contact with the commutator segments at the instant in which the current reverses its direction within the armature coil.* This is not at a position exactly half way between the two magnetic field poles, as might be supposed, on account of the *distortion of the flux of the field poles due to the cross-magnetizing effect of the armature coils and core.* As the commutator moves under the brushes and the brushes change contact with the commutator segments, each armature coil is successively short-circuited by the brushes, and it is essential that this short-circuiting takes place when the current in the coil is at its lowest ebb. The simplest way to determine this adjustment is to move the brushes around until the sparking is eliminated or reduced to a minimum. In many of the older types of dynamos it was necessary to move the rocker arm for every change in load on the machine. In more recent types this has been overcome by various methods of construction, principally by the use of compensating windings.

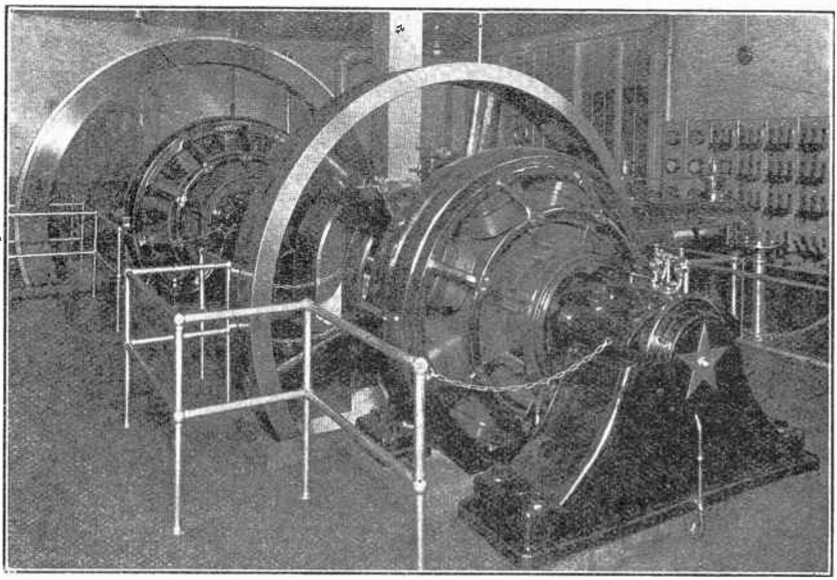


Fig. 81. Western Electric Type LD 250-K. W. Direct-Current Generator, with Compensating Windings, and Fly-Wheel.

The cross flux set up by the armature current is the cause of the distortion of the field flux which makes a shifting of the brushes necessary. It is possible to overcome this by providing an opposing magnetomotive force to counteract the distorting effect of the armature cross flux, and thus to make possible a central and permanent location of the brushes. This is accomplished by adding *compensating windings,* consisting of coils imbedded in slots in the surface of the field poles, and having a portion of the armature current passing through them.

In practical machines having many commutator segments the brushes generally short-circuit two segments at a time, overlapping a part of the segment on each side of these two. The resistance of each contact between each of the high-resistance brushes and a commutator segment decreases as the surface contact of the brush increases. There is also a difference in potential across the opposite ends of each brush. The end of the brush making contact first, following the direction of commutator rotation, is sometimes referred to as the *heel* of the brush. The other end is called the *tip* or *toe* of the brush. The difference of potential between heel and toe is equal to the self-induced emf. of the short-circuited armature coil. This effect is less noticeable when metal brushes are used. With metallic brushes there is little opposition to the flow of current until the contact between brush and commutator segment is broken. This forces the current to pass through the coil suddenly, and usually causes sparking. Hence the almost universal adoption of carbon brushes. Sometimes brushes are made of alternate layers of copper and carbon, the copper reducing the resistance between the armature and the external circuit, and the carbon reducing the sparking.

124. *The ratio of the power output of a generator to its power input is its percentage of efficiency.* In other words, the number of electrical horsepower which it can deliver, in proportion to the mechanical horsepower required to drive it, is an indication of the general efficiency of the apparatus. Generators are rated commercially according to their capacity, or the number of kilowatts which they can supply to an external circuit without excessive heating, and the potential difference that will be maintained across the brushes under these conditions. If the generator exceeds the maximum allowable heat, the insulation may break down.

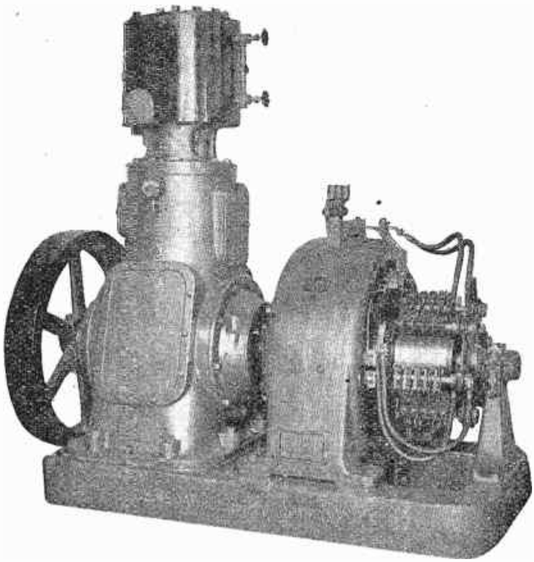


Fig. 82. Western Electric Marine Set, Direct-Current Generator and Steam Engine.

and considerable damage be done. The rating, however, is always considerably under the actual limit of capacity, so that within reasonable limitations generators may stand an overload of as much as fifty per cent. for a limited period of time. In the design of various types of generators consideration is given to the thickness of the field and armature cores, the breakdown voltage of the insulating materials used on the windings, the internal resistance of the windings, etc. Varnished cloth is frequently used for insulating the windings. Asbestos, paper, and cotton tape are also sometimes employed. They have, respectively, a breakdown voltage of about 7,500 volts, 1,500 volts, and 250 volts.

125. It is possible to increase the available current to be obtained from generators of low capacity by connecting two shunt generators in parallel across a circuit exactly as you would connect cells across the line, with the positive brushes to the positive of the line and the negative brushes to the negative of the line. As with the cells, this will increase the current but not the voltage. They may also be connected in

series, with an increase in voltage but no increase in current. Compound d. c. generators are also connected in parallel for greater current. When this is done an equalizing bar is used to stabilize the windings, and counteract effects of varying external load. This consists of a bar connected between brushes of like polarity, and to which the terminal of the series field winding is attached.

126. Starting with only residual magnetism, it is possible to furnish direct current for power for lights, for operating various kinds of electrical machinery on land or on board a vessel at sea, to draw from a dynamo power for this purpose, and at the same time to balance any loss of magnetism in the permanent magnets by the remagnetizing effects of the field windings. Modern sea-going ships are now supplied with an abundance of electric lights, and power for any other purposes desired, including the radio transmitter, from the d. c. generator, or *ship's dynamo* as it is usually called, which is located in the hold.

127. Three-wire systems are operated with but one generator by means of a third connection to the armature, instead of the use of two separate machines, as shown in figure 28. In early types of d. c. generators designed for this purpose an iron-core reactance coil was connected, as shown in figure 83*a*. Each side of the external circuit has an E. M. F. of, say, 110 volts, in which case the connections across the two outside wires give double that, or 220 volts. The center, or neutral wire, does not actually perform simultaneously as both a

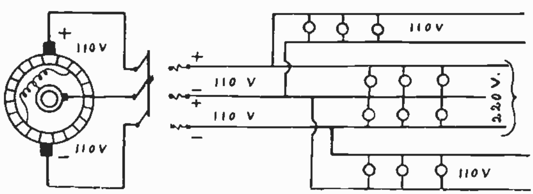


Fig. 83a. Early Type of Three-Wire Circuit Dynamo.

negative and positive path. It is either one or the other, according to the connections of the external circuit. When equal loads are placed on each half of the external circuit, it serves to connect these two loads across the outside wires in series with each other, dividing the voltage between them as two resistances in series parallel. In this case the system will work if the connection to the center brush is removed, as the current is passing clear across from the outside positive to the outside negative, by way of the neutral wire. In more

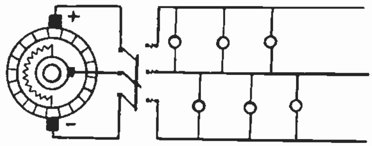


Fig. 83b. Modern Three-Wire Circuit Dynamo.

recent makes of machines for this kind of service, the neutral winding consists of one or more coils arranged as in figure 83*b*. These generate half as much voltage as the potential difference at the brushes. The action of the external neutral wire is the same with either type. The current in these neutral windings is not commuted, but is alternating current, which makes it possible for current to flow in either direction over the neutral wire. Connection of the third brush is accomplished by a slip ring mounted on the shaft in addition to the commutator. In many three-wire systems a generator providing a somewhat greater voltage than the maximum obtainable across the outside wires on the line is used; and this is shunted by what is known as a balancer. This consists of two dynamos connected in series with each other so that each may run as either a motor or generator. These

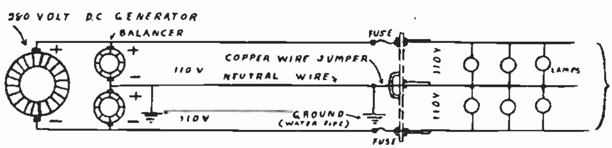


Fig. 83c. Grounded Three-Wire Direct-Current Power Line.

reverse according to the load on either side of the line and keep the system balanced. A heavy load on either side will produce a higher voltage on the opposite side, running the dynamo on that side as a motor, and feeding the heavier-loaded side. In cities where a large amount of lighting is required, the power for heavy motor work is supplied from a separate system, in order to prevent fluctuating of the lights. The neutral wire is invariably grounded at the supply station. The National Underwriters now recommend that the neutral also be grounded at the "service," omitting the middle fuse and bridging the gap with a jumper, as shown in figure 83*c*. Switch boxes and conduits are grounded to water pipes for protection from lightning and accidental high voltages. Where the fuse is used in the neutral wire at the entrance to buildings, this wire is not grounded at this point. Referring to the *Technological Paper of the Bureau of Standards, No. 108,* "The purpose of a ground connection is to keep some point in an electrical circuit at or near to the potential of the ground in order either that safety to life and property be secured, or that there be increased convenience and continuity of service. Ground may mean the soil itself or conducting bodies in contact with it. In many instances it is necessary that there be a considerable flow of current through the ground connection in order to prevent the potential of an electrical circuit from rising to a dangerously high value above the ground. The soil offers more or less resistance to this current flow, and this resistance determines in large measure the effectiveness of the ground in protecting against high voltage. With the middle of a three-wire system grounded at a single point, there is ordinarily no flow of current through the ground connection. If, however, an accidental ground should develop on an outer wire, current would flow through this accidental ground and the ground connection to the middle wire." Terrell Croft, in his *Wiring for Light and Power,* also says, "In a 110-220-volt three-wire system, with the neutral ungrounded, the maximum voltage to ground would be 220 volts. But with the neutral grounded, the maximum possible voltage to ground becomes 110 volts.. Hence it is evident that the life hazard is decreased by grounding the neutral. Every precaution should always be taken to insure that the potential of the neutral wire, which is normally grounded and is therefore at ground potential, never rises above ground potential. So long as the neutral wire is maintained at ground potential, there can be no voltage between this wire and the ground." The potential of the earth is taken as average. Less than the potential at the earth connection is called a negative charge, and greater a positive charge. Hence when anything is said to have a ground potential, it is understood to be as near neutral as possible, or at *zero* potential in relation to the earth. It is probable that the earth has a strong negative charge, but as all other potentials are considered as relative to this, and all instruments are affected similarly by it, the earth's potential is usually called zero.

128. A small direct-current generator with permanent-magnet field poles is frequently used for the field excitation of a high-powered alternator. This is usually mounted on the shaft of the alternator, as shown in figure 84, and considered a part of the complete machine. Contact to the revolving field is made through slip rings, and leads are brought out from the stationary armature. Sometimes the exciter is separately belt-driven. This has the advantage of preventing any drop in the speed of the alternator from causing a corresponding drop in the exciter voltage.

Figure 85a illustrates the fundamental principle of a single-phase alternator with a self-contained d. c. generator field exciter. In such a machine there is a noticeable drop in voltage as the current output is increased. To offset this

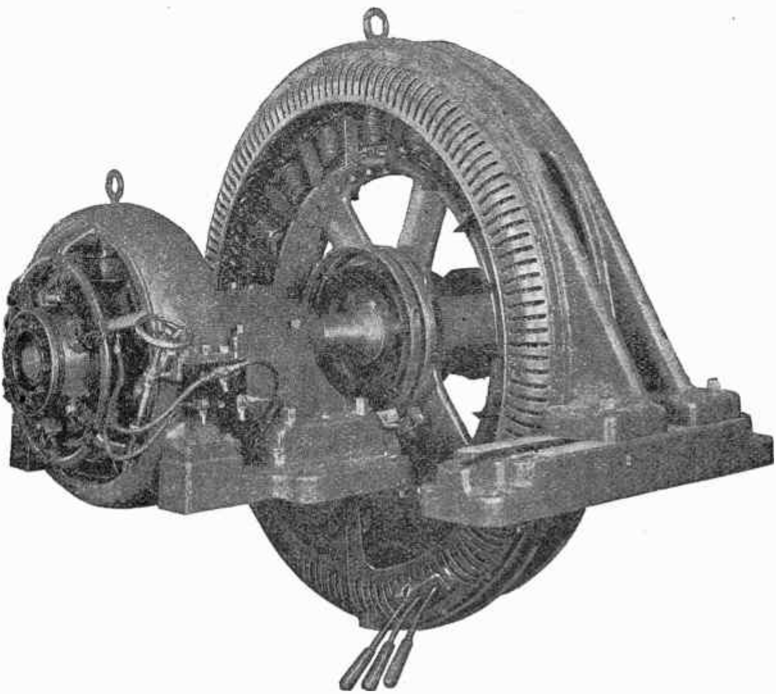


Fig. 84. Western Electric Alternator With Self-Contained Direct-Current Exciter Mounted on Shaft.

a series field winding is often used. The current from the alternator armature must of course be rectified before it can be used for field excitation. Various arrangements are used for this, one of the best known being a mechanical rectifier as illustrated in figure 85b. The rectifier consists of a type of commutator composed of two castings having staggered teeth. There are as many teeth as there are field poles in the alternator. The two castings are fitted together and insulated from each other. One terminal of the alternator armature is connected directly to one of the collector rings which supplies the output circuit. The other terminal is connected to one of the rectifier castings. The current from the armature then passes through one part of the rectifier, through the series field winding, and to the external circuit by way of the other collector ring. By tracing the circuit of figure 85b, it can be seen that the current in the external circuit reverses its direction, but that alternate alternations in only one direction can pass through the series field winding.

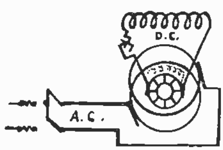


Fig. 85a. Single-Phase Alternator with Self-Contained D. C. Generator System of Field Excitation.

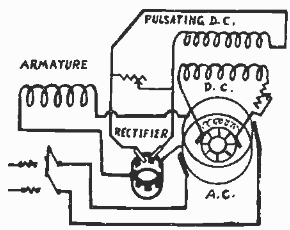


Fig. 85b. Compound Alternator with Rectified A. C. Series Field Winding.

A commutator is sometimes employed for rectifying the a. c. current of a three-phase alternator. The current for the field winding is usually obtained by means of auxiliary windings mounted in the same slots as the alternator armature. Brushes from these rest on a commutator of which alternate segments are connected to two slip rings feeding direct current to the field winding. Automatic compounding, to compensate for changes in load, is accomplished by the use of series transformers, as illustrated in figure 86. An increase in load, which draws more current through the primaries of the series transformers, will automatically feed additional energy back to the field winding to keep the voltage constant.

129. When current is supplied to an external circuit by a generator, connections are generally made by means of a two-blade or three-blade switch, according to the circuit, and fuses are invariably placed at the switch terminals to protect the external circuit from a possible overload of current. Fuses are also used in connection with the input switch at

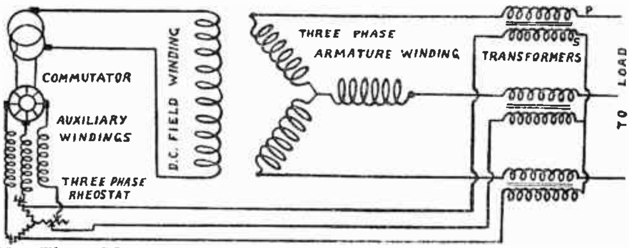


Fig. 86. Three-Phase Alternator With Self-Contained D. C. Field System.

the service. Fuses are of two general types, those known as the cartridge fuse, and the plug fuse. The cartridge fuse consists of a piece of wire, or flat strip of an alloy of lead and tin, imbedded in a mixture of asbestos and chalk, and held in a fiber cartridge-shaped container, having copper or brass caps at each end which fit into copper clips, thus making contact with the circuit. Some of these are renewable, with the caps screwing onto the ends. The plug fuse is made to screw into a block similar to a stationary lamp socket. It contains the piece of alloy, and works on the same principle. In each type, the alloy is accurately calibrated to pass only a given current before melting, and more than this amount will immediately "blow" the fuse, or melt the alloy. This calibrating is done by determining the resistance of the alloy, by varying both its size and its composition. In addition to the fuses, the circuits supplied with current from the generator are frequently protected further by a circuit-breaker, which is an automatic switch operated by means of an iron plunger in a solenoid. Circuit-breakers may be made to automatically open either a sigle-blade or a double-blade switch; and on either an overload or an underload of current. After opening, they must be closed by hand. In cities the maximum current which will be allowed to pass over certain sizes of

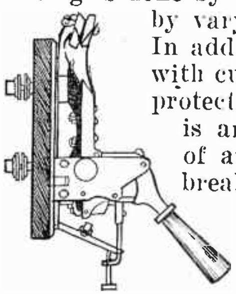


Fig. 87. Single - Blade Overload Circuit-Breaker.

wires is provided for in the Underwriters' rules, and fuses which pass no more than this current must be used, and circuit-breakers made to trip at this load.

Table of Amperes Allowable for Rubber Insulated Wire.

B. & S. Gauge	Amperes	B. & S. Gauge	Amperes
18	3	4	70
16	6	3	80
14	15	2	90
12	20	1	100
10	25	0	125
8	35	00	150
6	50	000	175
5	55	0000	200

CHAPTER 13

Motors

Shunt, Series and Compound Motors — Function of Motor Commutator — Direction of Rotation—Left-Hand Rule—Torque—Counter Emf.—Ohm's Law for Motors—Motor Losses—Efficiency—Commutating Plane—Speed Control of Motors—Compensating Windings—Interpole Motor—Induction Motor—Synchronous Motor—Repulsion Motor—Capacity of Motor—Electrodynamic Machinery Problems.

130. Motors are classified as direct or alternating-current machines, and as series, shunt, or compound. A d. c. generator and a d. c. motor are interchangeable; and an a. c. generator and a. c. motor are interchangeable. When the machine is operated by mechanical power and the rotor is revolved, it will deliver power in the form of electric current. When it is driven by electromagnetic force supplied by electric current, it will deliver energy in the form of mechanical power, which can be utilized to turn a shaft, drive machinery by means of a belt, or do other useful mechanical work. Sometimes minor changes are necessary in order to reverse the machines. If a self-excited shunt wound d. c. generator be connected at the brushes to a source of electric power, this current will pass through both the field winding and the armature. The direction of the current through the field winding is opposite to that when the machine was used as a generator. That which was the positive output brush is now the positive input brush. The current which passes through the armature is commuted, that is, the various loops of the armature exchange their connections to the source of current coming in, just as in the d. c. generator, they exchanged their connections to the output circuit. *The function of the commutator on a d. c. motor is to reverse the direction of the current in the armature at the proper instant so as to maintain the polarity of the armature windings in such relation to the field poles that there will be constant rotation of the armature.*

131. The *direction of rotation* of a motor may be determined by what is called the left-hand rule. This is illustrated in figure 88. *When the first finger of the left hand points in the direction of the lines of force, as indicated by a magnetic compass, and the second finger points in the direction from which the current flows, or toward the nega-*

tive of the source of power, the thumb, if extended level with the hand will indicate the direction of rotation of the revolving armature of the motor. This may be proved by several experiments showing the automatic twisting of two conductors, free to move, and placed parallel to each other. A charged wire has a tendency to move into a position which will allow its magnetic lines of force to run in the same direction as those of any other magnetic influence placed near to it, either a permanent magnet, an electromagnet, or

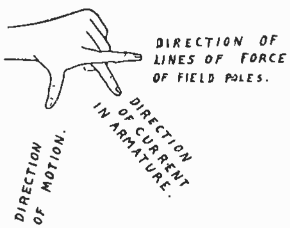


Fig. 88. Left-Hand Rule for Direction of Rotation of a d. c. Motor Armature.

a straight charged wire. If a charged wire be placed parallel to a bar magnet, the attraction will be for the wire to turn at right angles to the magnet, either toward the right or left, according to their relative polarity. The force is not in the wire or the iron, or the current itself. It is the *magnetism, the lines of force of which make an effort to run parallel to each other, and to pull the wire around so as to make this possible.* If a simple loop of wire, charged with current, be suspended so that it is free to move around, and a strong bar magnet be held close to this coil, one end of the bar magnet will repel the coil of wire, and the other end will attract it. It may be possible to cause the loop to turn clear around, or to revolve, by this method. A charged solenoid may be subsituted for the bar magnet with the same results. When two straight wires run parallel, they exhibit the laws of magnetic attraction and repulsion, if current passes through them. When the current flows through them in the same direction, the lines of force around them will be in the same direction, and the wires will attract each other. When current flows through them in opposite directions, their lines of force will be opposed to each other, north to north, or south to south, and the wires will repel each other.

132. The law of attraction and repulsion, as the source of rotation of motors, may be further illustrated by changing the connections to Faraday's disc, illustrated in figure 37. If electric current be sent through the wires connected to the external circuit, instead of taken from them, the disc will *revolve*. This is sometimes referred to as *Barlow's wheel*. If the direction of the current through the disc is reversed the disc will turn in the opposite direction. Or, if the horseshoe magnet be turned around so that it presents its north and south poles to opposite sides of the disc, the disc will reverse its direction. But if both are reversed, the direction of rotation will remain the same as before, because the relation between the two has not been changed.

133. Various types of armature windings are used for d. c. motors, these frequently being the distinguishing characteristic of the motors made by different manufacturers.* The drum armature, mounted on either a core of laminated sheets of steel, or on a spider, is most common; and the closed-coil windings are much preferred to the open-coil types. The losses due to heat and hysteresis are the same whether the dynamo is operated as a generator or as a motor. The distortion of the magnetic flux makes necessary the same relation between the brushes of the motor and the armature as in the generator, with the exception that the commutating plane will be at a spot to one side of the neutral plane exactly opposite to that when the machine is used for a generator. In the generator the commutating plane is in advance, in direction of rotation, of the neutral plane; while in the motor it is backward against the direction of rotation. This is on account of the distortion mentioned in para-

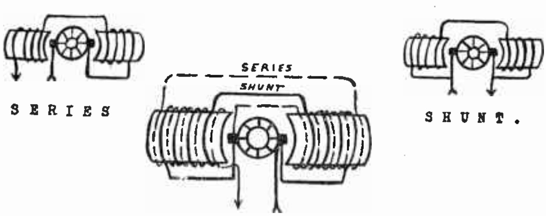


Fig. 89. Bipolar d. c. Motors, Shunt, Series and Compound.

*Note—Fig. 69, with current input from the line instead of current output to the line, is a simple diagram of a shunt-wound d. c. motor, and Fig. 71 of a compound d. c. motor.

graph 123. The distortion of the field flux by the cross-magnetic influence of the current in the armature wires, and the effort of these lines of force to unite and move in the same dirction produces the "drag," or pull, which causes the armature to turn. The lines of force passing from one field magnet to the other are "bent" in a curve, which is against the direction of rotation of the motor. There is a tendency for these bent lines of force to flatten out into their original position, as they make an effort to turn in the same direction as the lines of force of the armature, and the armature flux makes an effort to turn in the same direction as the field flux as it flattens out. The combined effect of this pulling and twisting of the magnetic lines of force is called the *torque* of the motor, or its *turning effort.* When one armature loop has arrived in a position which encompasses the greatest number of lines of force of the field flux, or the same number of lines of force as it produces itself, *its turning effort ceases;* and *if it turns beyond this point it will have a tendency to reverse the motion, and move backward.* Therefore, to procure *continuous rotation,* it is necessary to *reverse the direction of the current* exactly at the position where the change in turning effort would take place. Naturally, *the strength of the torque depends upon the strength of the magnetic flux of the field poles and the strength of the magnetic lines of force surrounding the armature coils.* When the load on the motor is increased, the current drawn from the supply line is increased, and the torque also increases in proportion, and the motor continues to turn, and takes care of the load.

134. When the motor armature is revolving through the flux of the field poles, producing mechanical power, it is simultaneously acting as a generator. The armature coils cutting through the field flux, pick up energy which produces an E. M. F. in an opposite direction to the flow of the current taken from the supply line. As in the generator, the strength of this E. M. F. is determined by the number of loops of wire being revolved, their manner of winding on the armature core, the speed of rotation, and the strength of the field through which they pass. The current flowing through the armature, then, depends upon the *difference* between the applied voltage and the counter emf. produced by the rotating of the armature. *If the counter emf. were to equal the applied E. M. F. no current would flow.* Reverting to our allusion to water in a pipe, as an illus-

tration of electric current along a wire, the effect of the counter emf. on the armature current of a d. c. motor is similar to placing a counter pressure at the outlet of the water pipe. With a given size of pipe and a given pressure at the reservoir, the quantity of water which could flow through the pipe would be in proportion to the difference between the pressure at the reservoir and the back pressure working against this. It is obvious that the applied emf. must always exceed the counter emf., and the difference between them is due to the same thing which causes the "drop" in the generator armature, viz., the armature resistance. Hence we have *Ohm's law for motors,* with e representing counter emf.

$$e = E - (I \times r \text{ of armature})$$

$$\text{Applied E. M. F.} = (I \times r \text{ of armature}) + e$$

$$\text{Armature volt drop} = E - e$$

$$\text{Current through armature} = \frac{\text{armature volt drop}}{\text{armature r}}.$$

$$\text{Current through field} = \frac{\text{applied E. M. F.}}{\text{field r}}$$

Power loss in armature = armature volt drop × armature current.

Power loss in field = Applied E. M. F. × field current.

Total losses in motor = watts lost in armature + watts lost in field + watts lost due to friction, eddy currents, etc.

135. The speed of a motor varies more or less under variation of load, and the counter emf. developed is always in proportion, so that the armature drop and counter emf. are equal to the applied E.M.F.; and as the motor accommodâtes itself to different loads, the current flowing in the armature varies with the developed counter emf., due to the speed of the motor, and only sufficient current to handle the load is taken from the line. When the motor is run without load its speed is increased, and the counter emf. is increased, so that a small amount of current is flowing in the armature. When a load is applied to the pulley, or shaft, the speed is lowered, less counter emf. is developed, and more current flows in the armature, in-

creasing the torque, and hence the pulling power of the motor. It will be seen that the power which a motor draws from the supply lines is directly in proportion to the work which it is required to do.

136. *The mechanical power of a motor is dependent upon the speed of the armature combined with the torque, and may be determined by finding the product of the counter emf. and the current flowing in the armature, or power developed* = e × I. This includes the losses due to heat, friction, eddy currents, etc. So the *power output of a motor is equal to the power developed minus losses.* The *efficiency* of a motor is therefore as follows:

$$\text{Efficiency} = \frac{\text{power output}}{\text{power input}}$$

The power input is the sum of the watts drawn by the armature and the watts drawn by the field.

Watts drawn by the armature = applied E. M. F. × armature current.

Watts drawn by the field = applied E. M. F. × field current.

137. The *shunt motor* has a field winding of many turns of fine wire, having high resistance; and, being connected across the brushes, this winding passes only a portion of the current of the line. It gives a slower starting torque than a series motor, but maintains a fairly constant speed under varying loads. It will turn in the same direction in which it would be turned if operated as a generator. To reverse its direction, connections to either field or armature winding alone must be changed. A *series d. c. motor,* having its field winding directly in series with the line supplying current to the armature, is composed of heavier wire. It starts up rapidly, but varies its speed with every change in load placed upon it. In fact, if allowed to run without load or some controlling resistance, it may "run away," and wreck itself. The series motor turns in the opposite direction from that in which it would be turned as a generator. Compared to the shunt motor, it has a higher torque at slow speed and a lower torque at high speed and is especially adapted to such work as driving street cars, lifting cranes, etc. Many small electric fans are also run by series motors.

Street cars employ two series motors in series for starting, the resistance being reduced by throwing them in parallel by means of a switch after the car has been started.

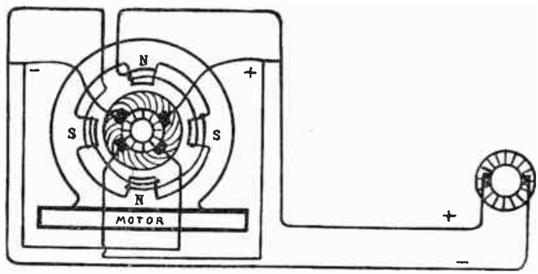


Fig. 90. Wiring Diagram of Four-Pole d. c. Shunt Motor.

138. Compound windings for dynamos are classified as accumulative, or cumulative as it is sometimes called, and differential. When the series field winding is arranged so that its magnetic flux is in the same direction as that of the shunt field winding, the lines of force unite, and we have an accumulative winding. When the series field is wound so that its magnetic flux is opposite to that of the shunt winding, the separate magnetic fields oppose each other, and this is called a differential winding. An accumulative wound motor has a greater starting speed than one with a differential winding, but will vary its speed more, under change of load, than the differential motor. The differential wound motor has a high starting torque, and will give a more constant speed.

139. Speed regulation of motors, after they have been started is usually accomplished with a rheostat. *When the resistance in series with the field winding of a shunt d. c. motor is increased, the speed of the motor is increased,* because by reducing the amount of current in the field winding, we also reduce the counter emf. *When resistance is cut out the speed of the motor is decreased,* on account of the increased counter emf. produced by the increase in current in the field winding. Figure 93 shows speed control of series motors. At A, the rheostat is subjected to the heating effect of the full running current. This is wasteful. Being in series with the armature, as well as the field, increasing resistance reduces speed. At B, increasing resistance sends more current through the field winding, and speed is re-

duced. C illustrates the most economical method of varying the magnetic strength of the field winding, and hence the speed.

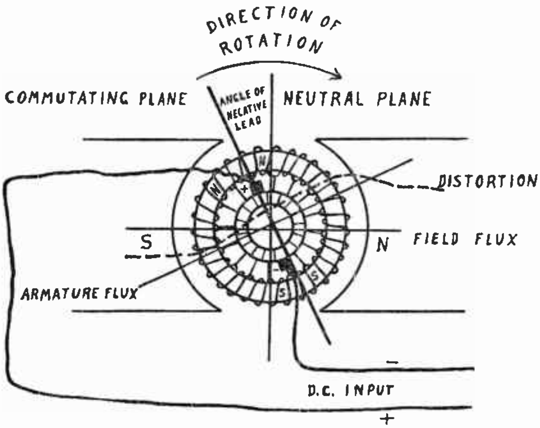


Fig. 91. Effect of Distortion of Motor Field.

140. Most dynamos of any size are operated on ball bearings; and with motors, where speed and low frictional losses are desired, this is especially important. Oil cups are located so as to feed oil into the bearings in the proper amount. Sparking at the motor commutator may be caused by the same conditions which would cause sparking if the machine were being run as a generator. It is necessary to adjust the brushes to the proper commutating plane, which is always to one side of the point midway between the field poles. Some d. c. motors have compensating windings, which counteract sparking at the commutator. These consist of a few turns of wire connected in shunt to the brushes, as explained in paragraph 123. Where the dynamo is constructed especially for service as a motor this compensating winding generally takes the form of separate poles, or *interpoles,* between the regular field poles, instead of the winding imbedded on the face of the field poles, as referred to in paragraph 123.

141. The speed of shunt motors may be varied, aside from the field rheostat method, if provision is made for moving the field poles mechanically. Certain types of motors are made with this mechanical arrangement. One type has the

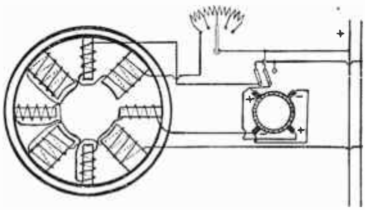


Fig. 92a. Wiring Diagram of Interpole Shunt Motor.

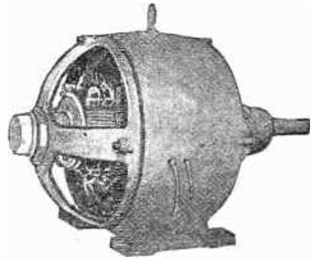


Fig. 92b. Four-Pole Interpole d. c. Shunt Motor.

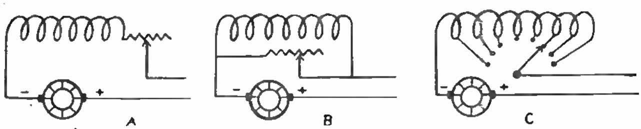


Fig. 93. Methods of Controlling the Field Strength of Series Motors.

cores of the field coils movable, while the windings are mounted on hollow tubes. The cores are mechanically controlled by a rotating wheel-like handle attached to the outside of the motor case. When the iron cores are lowered in the windings, their magnetism is increased; and when they are raised, the magnetic field is weakened. Another type lengthens the air gap between the revolving armature and the field windings by moving the armature backward and forward inside of the case.

142. The percentage of variation of speed, on full load and no load, is called the speed regulation of the motor. This is equal to the no-load speed minus the full-load speed, divided by the no-load speed. That is, of course, with a fixed setting of the field adjustment or regulation.

$$\text{Speed regulation percentage} = \frac{\text{no-load speed} - \text{full-load speed}}{\text{no-load speed}}$$

Information regarding the performance of the motor is usually furnished by the manufacturer in the form of a characteristic curve, and this accompanies the motor when purchased. The characteristic curve of a motor shows on a graph the relation between the input amperes, the R. P. M., the torque in foot-pounds, and the percentage of output power. By marking the point where these intersect at right angles on the cross-section paper, we make a curve which indicates the relation between these various factors. For instance, in figure 94, with 25 per cent output, full load, we have 7.5 amperes and 11 foot-pounds torque; at 50 per cent., 14.1 amperes and 23 foot-pounds torque; at 75 per cent., 40.1 amperes and 35 foot-pounds torque, etc. As the current drawn is increased, the torque is increased, with a higher percentage of power output.

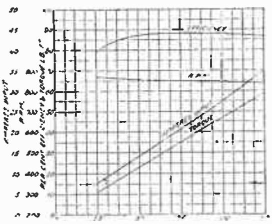


Fig. 94. Characteristic Curve of the General Electric Company's Type R. C. 75.-H. P. 230-Volt d. c. Shunt Motor.

143. Motors constructed to run on an alternating current may be divided into two general groups, namely *synchronous* and *non-synchronous*. The latter are usually called induction motors. The *induction motor* is operated on the transformer principle. While it might not be very practical to do so, from a mechanical standpoint, it is possible to reverse a revolving armature alternator, short-circuit the collector rings, and by sending alternating current through its field windings, to cause it to revolve as a motor. The armature is not connected to any external source of power, as was the case with the d. c. motor armature. Its sole source of energy is that picked up by induction from the "revolving" magnetism of the field and it is pulled around by this force. When one considers how an alternating current will alternately reverse the polarity of each field pole, it can be seen how the magnetic flux will actually rotate, as the lines of force pass continually to one south pole from a north pole, and so on around the inside of the frame, if there are more than two poles. A compass placed in the center of this field will spin. Induction motors may be made to operate on either single-phase or polyphase alternating current. In the polyphase machine, additional sets of poles are added for each phase, each set being wound in opposite direction, to procure continuous rotation of the flux. These motors

may have the usual wire-wound armature, or they may be constructed on the principle known as the *"squirrel cage."* The "squirrel cage" consists of a hollow laminated steel armature core, on which are mounted a number of copper bars, or strips, parallel to the shaft, and held in place by a copper ring fastened on each end of the drum. Current from the revolving field is induced into these copper bars, and an emf. and a counter emf. are set up, and the "cage" rotates, and turns pulleys, and does work. Single-phase induction motors require to be started by hand, or some auxiliary method, but will continue to rotate after once started. This is because the single-phase rotating field has a tendency to produce a torque of equal strength in two opposite directions. They will also stop at some particular torque, if overloaded. Polyphase induction motors simply vary speed on change of load, but do not stop. With the induction motor, the speed of the rotor is never equal to the frequency of the rotating magnetic field as there would be no cutting of the lines of force if this were the case. The difference between the synchronous speed and the rotor speed is called the "slip" of the motor. Synchronous speed is the product of the current frequency and the number of pairs of field poles. At no load the slip is very slight and the speed is nearly synchronous. The greater the load, the greater the torque required, and the greater the slip. The rotor current, hence the torque developed, depends on the percentage of slip.

$$\text{Slip} = \frac{\text{synchronous speed} - \text{actual speed}}{\text{synchronous speed}}$$

$$\text{Speed in rpm} = \frac{120 \times f \times (1.-S)}{P}$$

f = current frequency per second.
S = percentage of slip.
P = number of field poles.

144. The *synchronous motor* requires direct-current field excitation, and employs alternating current for its armature. Referring to figure 42, if alternating current were supplied to the loop of wire instead of taken from it, the loop would rotate. In practice, synchronous motors are generally constructed with a rotating field, a small d. c. generator

on the same shaft, and a stationary armature. Figure 85a, with the a. c. reversed, would be a diagram of such a motor. The synchronous motor runs in synchronism with the a. c. power supply and at a constant speed, regardless of load. The single-phase motor is not self-starting, but requires auxiliary apparatus to get it into step with the current. Otherwise it will only vibrate or "hunt" from one side to the other. Polyphase synchronous motors will start alone. Variation of field current, not being able to change the speed of the rotor, has the effect of changing the *phase* of the current in the armature, and by making it draw power with a "leading" current, the motor may be used to correct a low-power factor caused by induction motors on the line. On account of this it is sometimes referred to as a "synchronous condenser." As a practical piece of power machinery it is decidedly limited in usefulness, due to its having a low starting torque and the necessity of its having a large capacity for successful operation.

145. *A repulsion motor,* made to operate on alternating current, has an armature similar to that used on a d. c. motor; but this is not connected to the external supply line. The armature is short-circuited by a conductor which makes contact with the armature by way of brushes which rest on the commutator. As the armature increases in speed, these brushes are lifted by centrifugal force, and the armature continues to revolve as a simple induction motor. This type of motor is considered to be an improvement over the previously described induction motor, as it is not so difficult to start. Recent models of it are equipped with compensating pole windings, which still further increase its efficiency.

146. A type of motor made to operate on either direct or alternating current, and called a *"universal" motor* is popular for household appliances and small shops. The general appearance of it is similar to the d. c. motor, and might be puzzling to classify. The universal motor is a comparatively recent development in motor engineering. Its field coils are invariably laminated to reduce eddy currents and hysteresis, and the windings consist of a *small number* of turns of wire, which will reduce inductive reactance and a lagging power factor when the machine is operated on alternating current;

and which do not interfere in any way with the operation of the machine on direct current. The armature and commutator are exactly like those used in the ordinary d. c. motor.

Any *series motor,* equipped with compensating field windings, can be operated on either direct or alternating current, as its direction of rotation is not affected by a change of polarity at its terminals.

147. The *capacity* of motors is determined by the same conditions which determine the capacity of generators, and is understood to mean the work which they can be made to do without overheating. Motors are generally rated commercially in horsepower, this indicating the mechanical horsepower which they will develop at the pulley on full load. They also include on the name plate the voltage and current for which they are designed, and the revolutions per minute. Occasionally the output is designated in kilowatts, one K. W. being 1.34 H. P. The amount of current which a motor will take can be calculated, if the percentage of efficiency is known.

$$I = \frac{\text{mechanical horsepower} \times 746}{E \times \text{percentage of efficiency}} \text{ or } \frac{\text{K. W.} \times 1000}{E \times \text{p. c. of efficiency}}$$

The size of wire which should be used to conduct the current to the motor may be determined by the following:

$$\text{Circular mils} = \frac{\text{H. P.} \times 746 \times \text{length} \times K}{E \times \text{volt drop} \times \text{p. c. of efficiency}}$$

The horsepower developed by a motor is equal to the product of the current, voltage and percentage of efficiency, divided by 746.

148. Due to the fact that it is necessary to accumulate counter emf. in the motor before it can reach its normal speed, some device for controlling the current passing into the armature during starting is necessary for motors of any size. When the motor is standing still there is no counter emf. At the instant that current is sent into the armature $I = \frac{E}{R}$ is true, but after the armature has started

to revolve this is no longer correct, current then being equal to $I = \frac{E - e}{R}$. The current decreases with the speed of the armature, the counter emf. serving as a sort of automatic resistance, decreasing the current as the speed is increased. It is then necessary to employ more energy to start a motor than to keep it going after it has been started, and also, it is necessary to prevent an excessive amount of current, which might burn out the armature coils, from passing into the armature before the retarding counter emf. has been built up. Various types of starting devices are employed for this purpose. Chapter 14 deals with motor starters.

ELECTRODYNAMIC MACHINERY PROBLEMS

Alternators

1. What is the frequency of a 12-pole alternator making 1200 r. p. m.?

Answer. 120 cycles.

2. A separately-excited alternator, run by a d. c. motor, and installed as a part of a radio transmitter, gives a voltmeter reading across its brushes of 350 volts on no load. On full load it gives a reading of only 215 volts. What is its percentage of voltage regulation?

Answer. .628, or 63 per cent.

3. A 120-cycle alternator generates an E. M. F. of 500 volts, and is connected to supply power to an external circuit having a resistance of 50 ohms and an inductance of .05 henry. What is the power factor?

Answer. 79 per cent.

4. A 120-cycle 110-volt alternator is connected to an external circuit having 10 ohms resistance and 5 ohms reactance. What will be the reading of an ammeter connected in series in the external circuit?

Answer. 9.8 amperes.

5. An A. C. generator is rated as ½ K. W. 60 cycle, and 125 volts. What will be its capacity in amperes?

Answer. 4 amperes.

D. C. Generators.

6. A series self-excited d. c. generator having .04 ohm armature resistance and .05 ohm field resistance, is required to deliver current to a motor having a resistance of 6 ohms and drawing 10 amperes. The resistance of the wires between the generator and the motor is .5 ohm. What is the potential difference of the generator brushes?

Answer. 65.5 volts.

7. Five 200-watt lamps and a ½ H. P. motor are connected across one side of a 220-110-volt three-wire d. c. power system. A 12-ohm soldering iron, a storage battery charging outfit drawing 2 amperes, and four 75-watt lamps are connected across the other side. What would be the rating in current-carrying capacity of fuses suitable to insert in the three-blade switch block?

Answer. 15 amperes.

8. A self-excited shunt-wound generator provides current for lighting 80 incandescent lamps connected in parallel across the circuit at a distance from the generator. The lamps are rated at 55 watts, 110 volts. The resistance of the line is .03 ohm, the resistance of the generator field windings is 25 ohms, and the armature resistance .04 ohm.

(a) How much current is required for one lamp?
Answer. .5 ampere.

(b) How much current is consumed by all the lamps?
Answer. 40 amperes.

(c) What is the potential difference at the brushes?
Answer. 111.2 volts.

(d) What is the total E. M. F. generated?
Answer. 112.97 volts.

(e) How many watts are lost in the armature?
Answer. 78.58 watts.

(f) What is the power furnished to the lamps?
Answer. 4.4 K. W.

9. A compound d. c. generator, located in the dynamo room on board a vessel, supplies power to the motor generator in the radio operating room on the upper deck. It

also supplies power to the ship's lights, there being 200 lamps connected in parallel, each having a resistance of 200 ohms, and requiring 110 volts. The motor in the radio room requires 1 H. P. input to drive it, and operates on 110 volts. The resistance of the leads from the dynamo room is .01 ohm; the resistance of shunt field of the d. c. generator is 40 ohms, and of the series field .02 ohms, and of the armature .03 ohm.

(a) What is the line drop?
Answer. 1.16 volts.

(b) What is the drop in the armature?
Answer. 3.58 volts.

(c) How many volts are dropped in the series field?
Answer. 2.33 volts.

(d) What is the potential difference at the terminals?
Answer. 111.16 volts.

(e) What is the potential difference at the brushes?
Answer. 113.49 volts.

(f) What is the total E. M. F. generated?
Answer. 117.07 volts.

(g) How many watts lost on the lead?
Answer. 136.37 watts.

(h) What is the total power supplied by the generator?
Answer. 12.8 K. W.

10. If it takes 19 H. P. to drive the above generator, what is its efficiency?

Answer. 90 per cent.

Motors.

11. If a shunt-wound d. c. motor has an armature resistance of 2.5 ohms, and a field resistance of 112 ohms, and develops 225 volts counter emf. when operated on a 250-volt supply line, what current does it draw?

Answer. 12.23 amperes.

12. (a) What is the total mechanical power produced by the above motor?

Answer. 3 H. P.

(b) What is its total power loss if there is a loss of 50 watts due to friction, eddy currents, etc.?

Answer. 857.5 watts.

(c) What is its efficiency?

Answer. 71 per cent.

13. What is the speed regulation percentage of a d. c. shunt motor which runs at 1,600 r. p. m. on full load, and speeds up to 1,800 r. p. m. on no load?

Answer. 11 per cent.

14. What counter emf. is being developed by a d. c. shunt-wound 110-volt motor, having an armature resistance of .5 ohm, when running at a speed which permits it to draw 15 amperes of current?

Answer. 102.5 volts.

15. How many mechanical horsepower are developed by a d. c. motor operating on a 220-volt line, and having an armature resistance of 2.5 ohms, when running at such a speed that it draws 20 amperes?

Answer. 4.5 H. P.

16. A 2 H. P. d. c. motor is situated 90 feet from a three-wire power switch, across the outside terminals of which a voltmeter gives a reading of 225 volts. The motor is rated as 85 per cent efficient, and there should be 220 volts across its brushes.

(a) How much current will the motor draw?

Answer. 7.9 amperes.

(b) What would be the smallest size of rubber insulated annealed copper wire that could be safely used for the two leads connecting the motor to the switch?

Answer. Number 15.

17. What would be the speed of a 4-pole, 60-cycle, non-synchronous induction motor having a slip at full speed of 6 per cent.?

Answer. 1692 r. p. m.

CHAPTER 14

Motor Starters

Starting Rheostat—Starting Box—Automatic Motor Starters—Polarity of Power Line—A. c. Phase Splitter—Three-Phase Starter

149. As explained in paragraph 148, some form of controlling resistance is required for starting a motor, in order that too much current does not rush into the armature before the counter emf. has been developed, and damage the machine. For comparatively low-powered shunt d. c. motors, a simple starting rheostat, such as that illustrated in figure 95, is often employed. The contact arm is moved slowly across the contact points by hand, allowing the counter emf. to generate gradually. A strong electromagnet, connected in series with the field winding, then

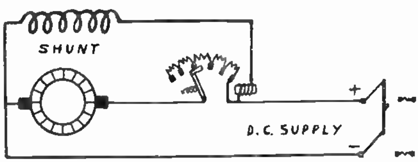


Fig. 95. Simple Starting Rheostat.

holds the arm in position as long as current flows through the field. When the switch is opened, or if an open occurs in the field winding, the electromagnet releases the arm, and it is drawn back to its starting position by a spring. On account of its functions, the magnet is sometimes called a *no-voltage no-field release magnet*. As can be seen, this type of rheostat merely cuts the resistance in or out of the circuit; and that which is cut out is inoperative. In figures 96 and 97 are shown two slightly different types of hand

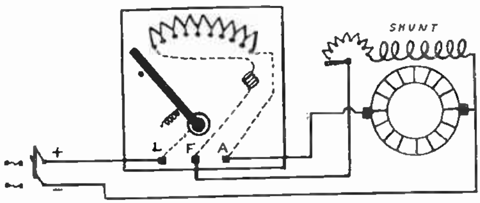


Fig. 96. Three-Terminal Starting Box (Cutler-Hammer).

operated motor starters, or *starting boxes* as they are usually called, in which the resistance is in continuous use.* The only difference between these two starters is the manner of connecting them to the main line. As the resistance is gradually *cut out* of the armature circuit, it is *cut into*

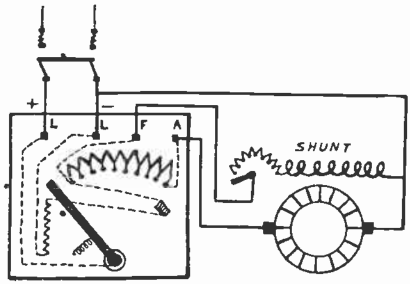


Fig. 97. Four-Terminal Starting Box (General Electric)

the field circuit, so that as we progress in starting the motor, we are decreasing the armature resistance and increasing the field resistance. This gives a smooth starting of the motor, with an automatic balance between the armature and the field windings.

150. There are several makes of starting rheostats and starting boxes on the market.

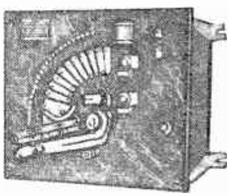


Fig. 98a. Cutler-Hammer Compound Starter.

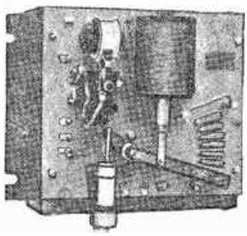


Fig. 98b. Cutler-Hammer Automatic Starter.

Fig. 98a illustrates a combination starter, which in one box contains resistances for both starting the motor, and for independent speed regulation by way of the field after the motor is started.

*Dotted lines indicate concealed wires. Resistance coils are actually inside box also.

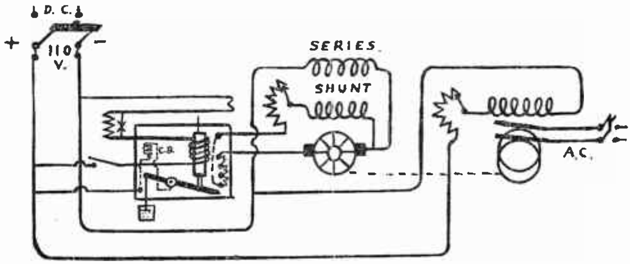


Fig. 99. Cutler-Hammer Automatic Starting Box Connected in Circuit With Compound Motor and Externally Excited Alternator.

A variation of figure 96 is made by the same manufacturer, in which the handle is drawn upwards over the contacts by an electromagnetic plunger. As the handle is raised or lowered, its motion is controlled by a small dash pot filled with oil. The electrical principle is the same as in the hand operated starter.

151. The separate rheostats and starting boxes are employed with motors used for driving machinery, for vehicles, etc., and in connection with radio transmitters of the assembled variety. Where the parts of a radio transmitter are mounted on a panel, as is the case with most modern ship installations, an automatic starter is included as a part of the general equipment on the panel. These automatic starters may vary considerably in design, but the fundamental principle is the same in all, no matter how complicated they may appear.*

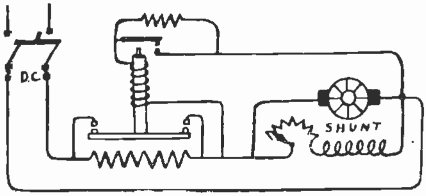


Fig. 100. Cutler-Hammer Panel-Mounted Single-Step Automatic Starter.

Figure 100 is a diagram of about the simplest type of panel automatic motor starter. This is the starter which is mounted on the panel of the Marconi ½-K. W. 120-cycle transmitter. At starting, the large resistance at the bottom is

*For various types of starters used in connection with particular types of transmitters, and comprising adaptations of the fundamental principles shown here, see Chapter 37.

connected in series with the armature. The current passing up through the solenoid induces magnetism which raises the T-shaped plunger. This closes the contacts at the opposite ends of the "T" and short-circuits the large resistance out of the circuit, the current passing by the path of least resistance. As the plunger rises a small rod, fastened to the center of it, mechanically lifts the contact above it and connects the smaller resistance at the top in series with the solenoid winding, thus protecting it from overheating. This is known as a one-step starter. In more elaborate types, two or more electromagnets usually accomplish about the same results successively. While the upper resistance coil is smaller mechanically it has a much greater ohmic resistance than the lower coil. It will be noticed that it forms a short-circuit around the motor armature.

Series motors may have a separate starting resistance, or they may be started with merely the field rheostat for control. This is generally the case with small fan motors, etc., which are frequently arranged as in figure 93a.

Starters will operate equally well connected on either the positive or negative side of the line. A simple method of determining the polarity of a power line which is not marked is to immerse two wires connected to its terminals in a glass of drinking water, being careful not to allow them to touch. *The negative terminal will bubble profusely,* while the water around the positive terminal assumes a bluish, milky appearance.

152. Starters for alternating-current motors vary according to the phase of the current. Single-phase motors, which will not start without some externally applied force, on account of the reversing effect of the single-phase current, may be started by any one of a number of different arrangements of inductance coils. One of these is known as a phase splitter. It has an inductance considerably higher than the motor armature, and this causes the current in the inductance coil to lag behind the current in the armature, producing

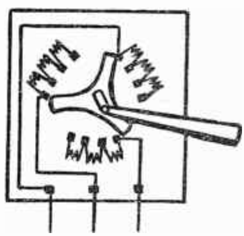


Fig. 101. Starter for Three-Phase Induction Motor.

what practically amounts to two different phases, and a continuously rotating field. After the motor has been started by means of the phase-splitter coil, the coil is thrown out of the circuit by a switch. A resistance box is generally employed for starting a three-phase motor, and provides a variable contact to three sets of resistance coils, there being one coil for each armature circuit. The resistance units are in series with the armature windings at starting, and are gradually cut out by rotation of the starter handle, until the rotor is short-circuited. At this point the motor has "picked up" its full speed.

CHAPTER 15

The Motor-Generator

Types of Motor-Generators—Protective Resistances and Condensers—Rotary Converter—Dynamotor—Motor-Generator Problem.

153. A *motor-generator* consists, obviously, of a motor and a generator coupled to one shaft, and considered as a single piece of machinery. Generally speaking, it may consist of about any kind of a motor and any kind of a generator. Such machines are employed in various places, for operating on direct current, and for changing direct current of one voltage to direct current of another voltage; for operating on alternating current, for the purpose of changing alternating current to direct current; or for operating on direct cur-

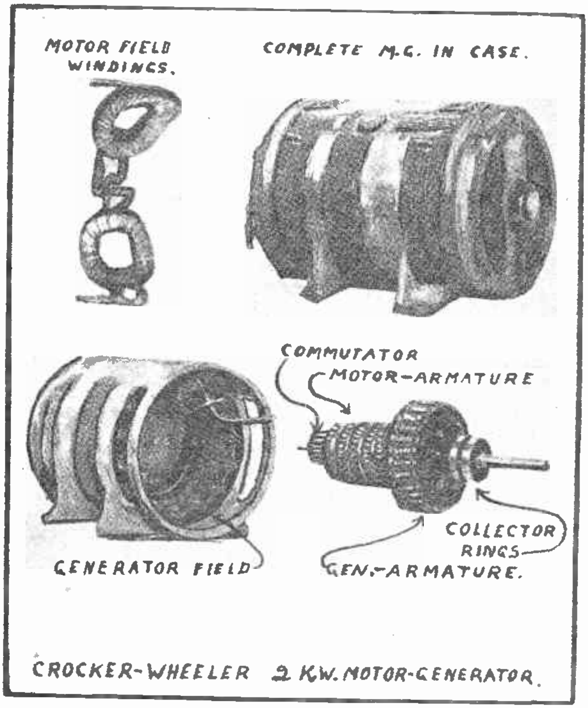


Fig. 102. Crocker-Wheeler 2-k. w. Motor-Generator used for producing Alternating Current for a Radio Transmitter.

rent, for the purpose of converting direct current into alternating current. In spark sets the motor-generator is understood to be a double machine consisting of a direct-current motor and an alternator coupled to the same shaft and covered by a single frame on which the field poles of the two machines are mounted. The motor in this compound machine is either a simple shunt wound, or of the differential type. The latter is to be preferred for driving the alternator to be used in radio transmitting on account of the smooth operation and small percentage of speed variation. With the motor-generator installed between the direct-current dynamo and the alternating-current radio apparatus, we find that between the main switch and the a. c. switch we have nothing but a mechanism for changing direct current into alternating current. It might seem that if we had an alternating current supply that this would not be necessary. Provided it were of the right frequency, it might be possible to use it;

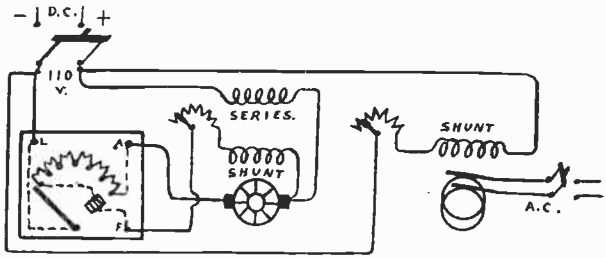


Fig. 103. Circuit Diagram of a Motor-Generator Consisting of Compound Motor, with a Cutler-Hammer Hand-Operated Starting-Box, and and Alternator Having Its Field Poles Energized by a Winding Shunted Around the Motor Connections.

but it would not be as easily under the control of the operator as when he has the alternator as part of his equipment; and the alternating current used for ordinary power purposes is generally of a lower frequency than that employed for charging the condensers of spark transmitters. With a direct current supply, the direct to alternating current motor-generator is indispensable.

The horsepower necessary to drive a single-phase alternator is equal to

$$\frac{\text{Gen. E.} \times \text{Gen. I} \times \text{power factor of Gen. output circuit}}{\text{Gen. efficiency} \times 746}$$

154. The usual field rheostats are connected to the windings of the motor and alternator respectively, and produce the same results described in previous chapters. The motor starter may take any of the forms explained in chapter 14. With the motor-generator connected as a part of the radio

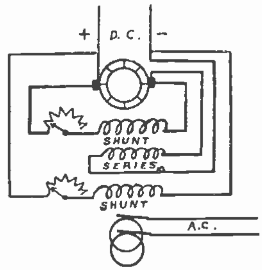


Fig. 104. D. C. to A. C. Motor-Generator Circuit With Starter Omitted for Simplicity.

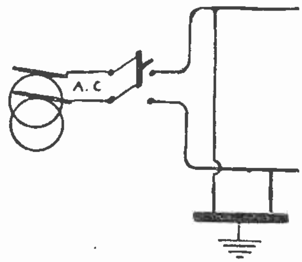


Fig. 105. Protective Resistance Rod Across Alternator Output.

transmitter we find one difficulty. When the wires of the transmitter are charged with high-voltage high-frequency current, it sometimes occurs that the windings of the motor pick up, by induction from them, magnetic lines of force that have penetrated the atmosphere; and that this overloads the motor windings and causes them to burn or "puncture," possibly doing considerable damage in places difficult to repair. To overcome this, a pair of protective condensers are connected to the motor brushes, and these are connected to the ground. Excessive potentials are thereby neutralized.

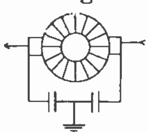


Fig. 106. Protective Condensers Connected to Motor Brushes.

The same kind of induction may take place in the wiring of the alternator circuit. In some obsolete types of installations a resistance rod was used for protection. A resistance rod consists of a piece of graphite of such resistance that the voltage usually employed in the apparatus cannot pass through it, but which will permit the escape of an overload. In modern transmitters preference is given to the condensers for protection against this kind of trouble.

155. Two machines, which might be rated as forms of motor-generators, are known as the rotary converter and the dynamotor. The *rotary converter* consists of an armature, having commutator and collector rings mounted on the same

shaft. Quoting from the *U. S. Signal Corps Pamphlet, No. 40,* "If connections are made to a pair of collector rings from opposite sides of a two-pole d. c. armature it will generate alternating current. At the same time, direct current can be taken from the commutator. In that case the machine is a *double-current* generator. If not driven by an engine, but connected to a d. c. circuit, it operates as a shunt motor

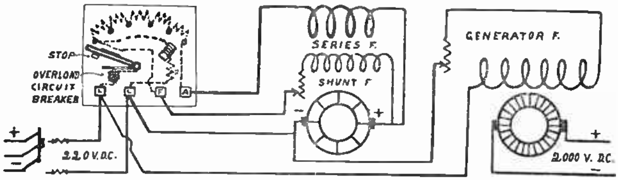


Fig. 107. Compound Motor and High-Potential D. C. Generator, Connected to G. E. Starting Box with Motor Series Field Controlled by Starter.

and can be used to generate alternating current. Operated on a. c. as a motor, it delivers d. c. The rotary converter has the advantage of accomplishing in a single machine what the motor-generator does in two. Its disadvantage is that the voltage at the generator end depends entirely on the

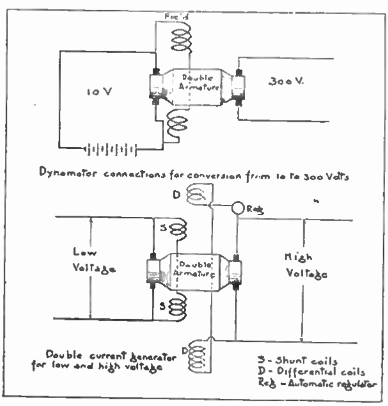


Fig. 108. Rotary Converter and Dynamotor.
(From U. S. Signal Corps Pamphlet No. 40.)

voltage supplied to it as a motor." Rotary converters may be supplied with power from any one of a number of sources, storage batteries being used in several cases for portable apparatus. The *dynamotor* consists of a double armature wound on a single core, one acting as the motor and the other as the generator; and there is but one set of field windings. Each armature winding is connected to a commutator, these being placed at opposite ends of the core. The dynamotor is used to raise the voltage of d. c. For instance, it is possible to raise the voltage of a supply taken from a 12-volt storage battery, by means of a dynamotor, to several hundred volts d. c. This has been found convenient in connection with vacuum-tube transmitters, radiotelephone outfits, etc.

156. Motor-generators for producing *direct current* are used extensively in modern vacuum-tube transmitters. In some cases they are designed to give two voltages, one much higher and the other lower than the main supply. Occasionally a direct-current generator is run by an alternating-current motor for this purpose. Figures 308, 309 and 310 illustrate direct-current motor-generators designed for use with vacuum-tube transmitters; and figure 311 shows a photograph of a dynamotor. The current produced by the alternator in the spark transmitter is of comparatively low voltage, and it is stepped up to many times its original potential by a *power transformer*. The care of the motor-generator is taken up in chapter 40.

PROBLEM

What would be the H. P. rating of a d. c. motor suitable for coupling to the driving shaft of a 125-volt single-phase a. c. generator, 83 per cent efficient and having a current capacity of 5 amps., when the power factor of the circuit supplied by the generator is 95 per cent.?

Answer. 1. H. P.

CHAPTER 16

Power Transformers

Step-up Transformer in Radio Transmitter—Types of Transformers—Ratio of Transformation—Step-down Transformer—Transformers on A. C. Power Lines—Resonant Transformers—Reactance Regulator—High-Frequency Discharge of Tesla and Oudin Coil

157. In order to cause electromagnetic waves to radiate from the antenna to great distances, it is necessary that electric current be forced onto the antenna at high pressure. The voltage of the alternator used with the "spark" set being low, it is found necessary to step it up to many times its original pressure. This is done by the process of electromagnetic induction; and the *step-up transformer* used for this purpose in the radio transmitter is known as the *power transformer*. Crabb's *Synonyms* states that "to transform is to transfigure," and to "transfigure is to make to pass over into another figure, or to put into another form." So, strictly speaking, the motor-generator, when used to transform direct current into alternating current, is a transformer. However, this term, when applied to electrical apparatus, is understood to mean a primary and secondary coil used for transferring energy into a secondary circuit, and generally "into another form," by the process of induction.

158. The transformer was one of the results of Faraday's experiments. Faraday's transformer consisted of an iron ring, one-half of which was wound with a primary coil and the other half with a secondary coil. We know that when a magnetic flux is moved in inductive relation to a wire, or the coil of wire moved in inductive relation to a magnetic flux, that a current will be induced to flow in the wire. We see this principle applied in the alternator, where the change in the lines of force is brought about by arranging the field magnets so that they are of alternate polarity, thus inducing current into the armature. In the transformer, one rush of current through the primary will cause one alternation of current to flow in the secondary. With the arrangement used by Faraday, this took place only once, on account of the primary being actuated by only a battery and a key. With the power transformer used as a part of the radio transmitter, the current is supplied in alternating form, and of course the alternations cause current to be induced into

the secondary as long as it is applied to the primary. The frequency is not stepped up or down; but the voltage is increased in proportion to the size and number of turns of wire

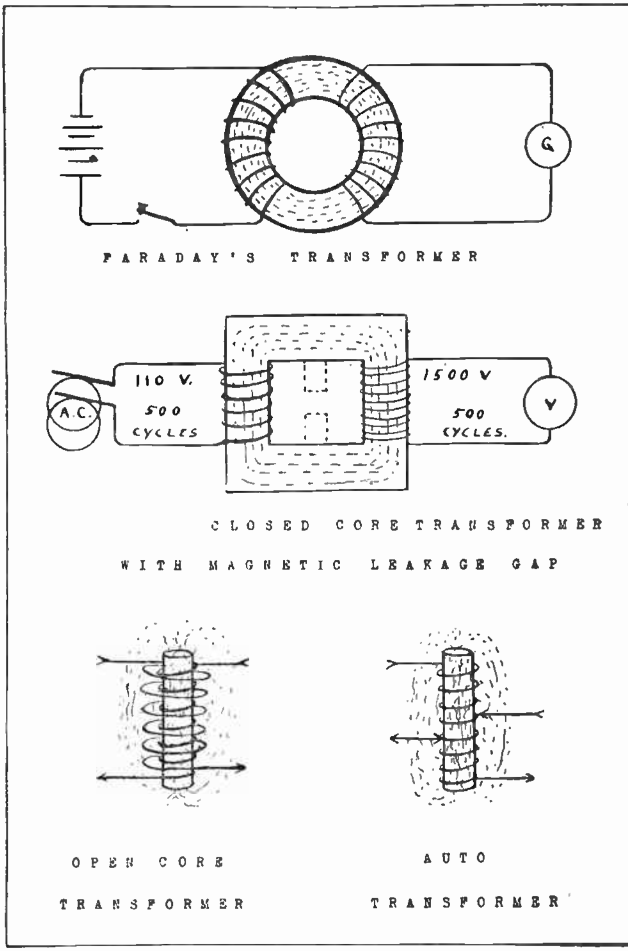


Fig. 109. Various Types of Transformers.

in the secondary as compared to those in the primary. The amount of current is reduced, so that the total wattage of the secondary circuit is invariably somewhat less than that in the primary. This is on account of losses in the transformer due to hysteresis, eddy currents and heat. Otherwise the power should be the same. The ratio of the secondary coils and voltage to the primary is known as the *ratio of transformation. The ratio of the voltage of the secondary is to the voltage of the primary as the ratio of the number of turns of wire in the secondary is to the number of turns of wire in the primary.* For instance, if there are 5,000 turns in the secondary, and 100 turns in the primary, the ratio of transformation will be such that the voltage in the secondary is 50 times as great as that in the primary. Suppose that one of the turns of the secondary should pick up exactly one volt, then the 5,000 turns would pick up 5,000 volts. The percentage of the power transferred into the secondary circuit in proportion to the power input of the primary circuit indicates the *efficiency* of the transformer.

159. To understand the action of the power transformer it is well to recall the definition of the *henry,* namely that amount of inductance in a circuit which will produce a back emf. of one volt when there is a current change of one ampere per second, or where a current of one ampere is surrounded by one hundred million lines of force, setting up a pressure of one volt. Therefore, if a primary coil has a current established in it which is varying at a certain rate per second, there will be built up around the coil a changing field of lines of force the flux density of which will depend upon the amount of current, the size and kind of wire used, and the number of turns in the wire. If the dimensions of the coil and the nature of the current are such that a flux density of 100,000,000 lines of force are obtained, then for each time this field cuts through the turns of the secondary coil, there will be produced in each turn one volt, showing that to increase the voltage from 110 to 15,000 volts, it is only necessary to know how many turns and the proper size of wire to use for the primary and secondary. Since a coil which would be capable of producing such a flux density would require a very large number of turns, would be expensive, and require a great deal of space, it has been found desirable to wind the coils over a core of iron, generally soft iron wire or laminated sheet iron, which readily becomes magnetized, and add more lines of force to those produced by the several turns. This makes it possible, in convenient form, to secure the correct flux density for any particular design of transformer. Take a 15,000-volt step-up transformer used with a ½-K. W.,

60-cycle transmitting apparatus which is operated on a d. c. supply of 110 volts. In this type of transformer the primary generally consists of approximately 220 turns, with an inductance of about .6 microhenrys, equaling about 60,000 lines of force, which will produce only a fraction of a volt in each turn of the secondary windings. If we depend upon an "air core" it will be necessary to build a secondary having over 300,000 turns of wire. If, however, we employ a soft iron core, we find that it is necessary to make only about 30,000 turns in our secondary in order to obtain the required 15,000 volts in the secondary circuit. We have raised the number of lines of force from approximately 60,000 to somewhere around 50,000,000 simply by the addition of the core.

160. A transformer wound with the primary and the secondary over the same core, as in the lower left hand drawing in figure 109, is known as an open-core transformer. This is the type of transformer used in the induction coil. It is called an open core because the magnetic path is open, and the lines of force pass from one end to the other, on their way back from north to south, through the air. A closed-coré transformer is one in which a complete metallic path is provided for the lines of force, as in the two upper drawings in figure 109. A more recent model is that shown in figure 111. This is called the shell core and is a type of closed core. It will be seen that in this core, the lines of force are provided with a metallic path shaped exactly like that which they would take were they permitted to pass through the air. Sometimes closed-core transformers are equipped with what is called a magnetic leakage gap. This is composed of two sections of the core projecting into the center of the frame; and in case of a sudden excess of current in the primary winding, or a short-circuit of the secondary, the magnetic leakage provided will keep the inductance of the primary so nearly constant that it is protected from burning out.

161. The wire used for power transformers is insulated, and the coils are well insulated from the core. In large transformers made to handle considerable power, cooling systems are used to reduce the loss due to heat. Transformers used for raising or lowering the voltage of city power lines are sometimes cooled by air blasts, and by water circulating systems. The most common cooling method is that of immersing the transformer in a fine grade of mineral oil, known

as transformer oil. This also increases the efficiency of the insulations. However, it may be considered as somewhat objectionable on account of being inflammable.

162. *Step-down transformers* are common in city and cross-country power circuits, but are little used in radio apparatus. It is usual to find *direct* current in the business, or "down town" section of a city, and alternating current in the suburbs. The *weight of copper wire required* to conduct a given amount of current a given distance, with the same drop in potential, or "line loss," is in inverse proportion to the square of the voltage. And the energy lost due to heat

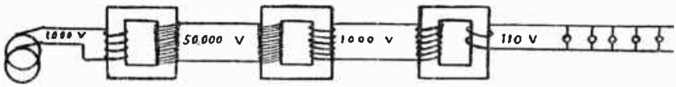


Fig. 110. System of Step-up and Step-down Transformers used in Transmitting Power.

created by overcoming the resistance of the line is in proportion to the current, or $I^2 R$. If the current is small, the heat loss will also be small. For instance, if 10 amperes are transmitted at 110 volts over a line having 5 ohms resistance, the *power* available will be $E \times I$, or 1,100 watts. The $I^2 R$ loss is $10^2 \times 5$, or 500 heat units. If we transmit 2 amperes at 550 volts over the same line, we will have the same *power* for doing work, but the loss will be only 4×5, or 20 units of heat. Therefore, by conducting current at extremely high voltage, say 50,000 or 60,000 volts, which is the potential used in transferring energy from Niagara Falls to the surrounding country, there is accomplished a *saving in copper* representing a small fortune. At this high voltage of course, the current cannot be used for city lighting and power purposes. It is stepped up in voltage at the power house, and *stepped down* at various points along the line where needed, by a series of step-down transformers. The reason then, for the high-voltage transmission lines, the use of alternating current, and the system of step-down transformers, is *economy in copper*. Smaller step-down transformers, generally with variable connections for securing different voltages, are used on city lighting circuits for such purposes as charging storage batteries, in combination with suitable rectifiers, for Christmas tree lights, operating toy trains of cars, etc.

163. It is possible to change the voltage of an alternating current by means of a device having only one winding. This is known as an *auto transformer*. The secondary circuit in this case is connected to the coil by taps, the position of which on the coil affect the ratio of transformation. This type is seldom used for stepping the voltage up, but is quite common as a step-down transformer. When it is desired to step the voltage of a two-phase or three-phase alternating current supply line up or down, it is customary to employ transformers having separate windings for each separate set of armature coils in the generator. These transformer coils may be connected in delta, star, etc., to correspond to the number of coils and phases in the generator. A three-wire power line supplied from a three-phase transformer will give exactly the same voltage across the two outside wires as from either one of them to the center wire.

164. In figure 111, a spark gap, having a condenser and inductance coil in series with it, is placed across the secondary of a step-up transformer. This will produce a brilliant discharge across the gap. It is found that by adding an iron core inductance coil, generally called a *reactance coil,* in series with the primary circuit of the transformer, we

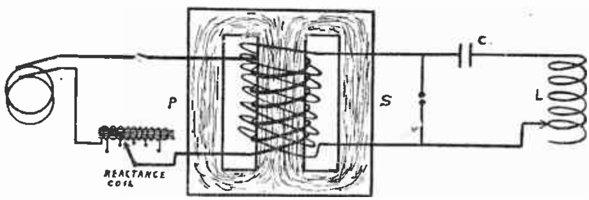


Fig. 111. Shell Transformer with Reactance Regulator.

can *tune* the transformer to a period to correspond with the frequency of the alternator; and also, within limitations, we can balance the impedence of both circuits of the transformer. This condition is called resonance, and this arrangement is known as a *tuned* transformer, or a *resonant transformer.* Transformers, tuned and untuned, large and small, with and without cores, are employed extensively in all forms of radio apparatus both for transmitting and receiving. *The particular function of the step-up transformer in the spark transmitter is to provide a high-voltage alternating current for use in charging the condensers, without the necessity of* *employing an alternator of the great bulk and costliness which would otherwise be required.* By using a reactance coil, with taps, as shown in figure 111, the *impedence* may be varied, and the *current* regulated accordingly.

The brilliant discharge across the spark gap is due to the extremely *high frequency* of the current in the condenser circuit. (See chapters 17 and 18.) The famous *Tesla coil,* popular for entertainments and amateur experiments, makes use of practically the same circuit as that illustrated in figure 111. In this a secondary coil of many more turns of wire is *inductively* coupled to L, and across this is a second spark gap, which may be made to produce a very spectacular electrical display. When the secondary coil is *conductively* coupled to L, the sparking will take place at the terminal of this coil, a large brass ball being usually arranged at this point to make the greatest display of fireworks." This is known as an *Oudin coil,* or *resonator.*

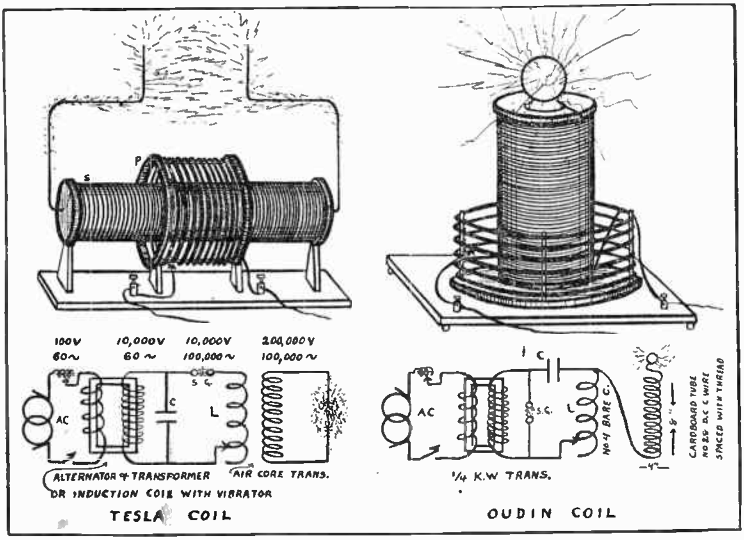


Fig. 112. High-Frequency Spark-Discharge Circuits.

The spark can be made to jump several feet from the brass ball to another piece of metal. On account of the extremely high frequency of this discharge, it is not considered dangerous to human life.

CHAPTER 17

Condensers

Construction of Various Types of Condensers—Electrostatic Field—Oscillating Current—Condenser Discharge Across Spark Gap—Damping—Oscillation Transformer—High-Frequency Circuits of Spark Transmitter—Table of Dielectric Constants—Definition of Farad—Effects of Condensers in Series and Parallel—Condenser Problems.

165. A condenser is a device having capacity for holding an electrostatic charge.

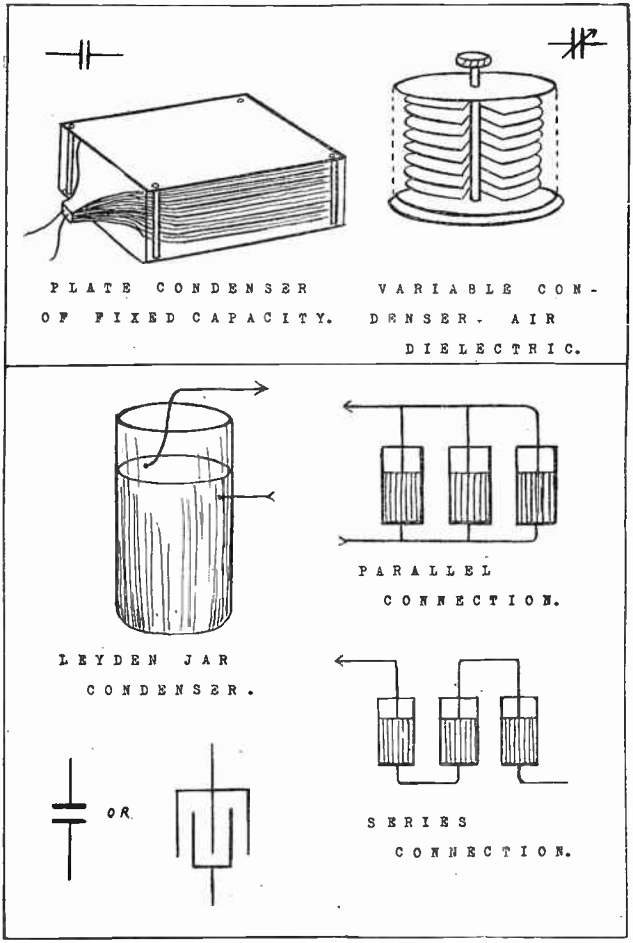


Fig. 113. Various Types of Condensers.

The earliest known condenser was the Leyden jar, invented in 1746 by Musschenbroek, and named after the Dutch town where it was originally manufactured. It consists of a glass jar or bottle, coated on the inside and outside with copper, or tinfoil, leaving about one-fourth of the surface of the glass at the upper edge of the jar bare. Later forms of condensers consist of alternate layers of conducting and insulating material pressed or rolled into compact form. Some of these are made of tinfoil and waxed paper. Others of copper and glass plates immersed in oil. Still others of copper and mica imbedded in wax. All of these are called fixed condensers, as they can not be varied. Another type is known as a variable condenser. In this there are two sets of plates connected alternately to posts which are insulated from each other, and one set of plates can be rotated. Variable condensers are seldom used for transmitting purposes. When they are, they are not infrequently

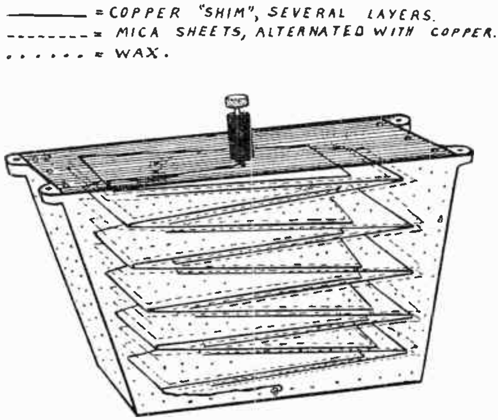


Fig. 114. Mica Condenser Consisting of Several Small Condensers in Series. (Capacity .004 mfd.)

immersed in oil. Small variable condensers are used extensively in receiving apparatus. In all of these the insulating material, be it glass, mica, waxed paper, oil or air, is called the *dielectric*. Condensers made to use for transmitting are usually referred to as high-potential condensers, because they are made to withstand the high voltages employed in radio transmitters.

166. A peculiarity of condensers is that when one is connected in a circuit with a charging source, such as a battery, as shown in figure 115, that it will store up a charge from this battery while the key is pressed, and discharge it when the key is released. In figure 115, the charge from the battery will create a positive strain on the upper plate of the condenser, and a negative condition of the lower plate. The plates are insulated from each other, so *current* cannot pass through the condenser. A difference of potential between the two sets of plates is produced, and the pressure or strain set up by this condition is called an *electrostatic field.* An electric charge is there; but it is, for the instant, motionless —in what might be called a state of *tension.* Condensers operate on the law of attraction of unlike charges and repelling of like charges. A negative charge on one plate will repel the negative electrons in the opposite plate, causing the latter to have a positive charge. This positive charge then has an attraction for the negative plate, reducing the potential of the latter. This can go on until the *back pressure* of the condenser equals the voltage of the charging current, at which stage there can be no further charge placed on the plates, and the condenser is said to be fully charged, or charged to the limit of its capacity. If the key, in figure 115, be raised, the electric energy stored up in the condenser during the charging period, will discharge around the circuit containing inductance and resistance. It will rush around and produce a negative charge on the *other side* of the condenser. This causes a positive condition on that plate which had been negative, and when the energy released at the discharge upon opening the key has charged the condenser from

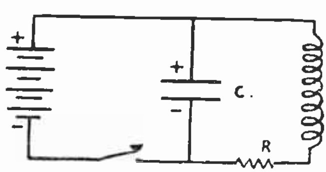


Fig. 115. Condenser Charge and Discharge Circuits.

the opposite side to the limit of its capacity, there will be another discharge around to the opposite side again, and this process will repeat itself until the energy is gradually dissipated in heat by the resistance of the circuit. Theoretically, were it not for the resistance of the circuit, this might go on forever. The movement of the current around the circuit during the discharge of the condenser is of an oscillating character, and is known as *oscillating current. The time period of each oscillation, hence the frequency, is determined by the amount of inductance and capacity in the circuit.* The *gradual decrease in amplitude* of each successive oscillation is determined principally by the amount of resistance in the circuit; and is called its *damping,* and the *number of oscillations* is determined by their *rate of damping.* They will continue until they have died down to zero.

If a spark gap be inserted in the discharge circuit of the condensor in place of the resistance coil illustrated in figure 115, the oscillatory discharge will jump across the gap with a brilliant spark. In this case the resistance is made variable by regulating the length of the gap between the two gap electrodes. Then the damping, and the number of oscillations will depend upon the resistance of the wire in the circuit, and of the air space in the gap. The condenser will charge until the pressure is sufficient to break down this air dielectric between the gap electrodes, and then the discharge will take place around and around the circuit, crossing the gap each time, producing a *"spark discharge."* If the electrodes of the gap are placed too far apart, so that when the condenser has been charged to its full capacity, it can not bridge the gap, it is likely to wreck the condenser. This damage usually takes the form of a "puncture" in which the pressure breaks a round hole through the dielectric, thus finding a way through to the other side of the circuit.

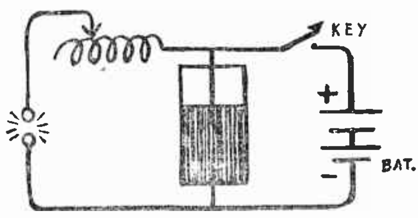


Fig. 116. Condenser Circuit with Spark Gap.

167. If we connect a condenser in circuit with the secondary of a high-voltage step-up transformer, we then have a condition which is the foundation of the usual type of "spark" radio transmitter. Each alternation of the gen-

erator in the power circuit transfers one alternation of magnified pressure into the secondary circuit, which charges the condenser. And there is one complete condenser discharge across the spark gap, in the form of a series of oscillations, or an oscillation train, for each alternation.

Fig. 117. Oscillation Train.

If we inductively couple a secondary coil to the inductance in the condenser discharge circuit, we then have an air-core transformer, known as the *oscillation transformer,* and with this connected in series with the antenna and the ground, we have the usual arrangement used for radio communication by means of damped waves. When oscillations take place in the primary of the oscillation transformer, they are conveyed by induction to the antenna circuit, and current flows in the latter circuit. The reason that current can flow in the antenna circuit is on account of the *capacity*

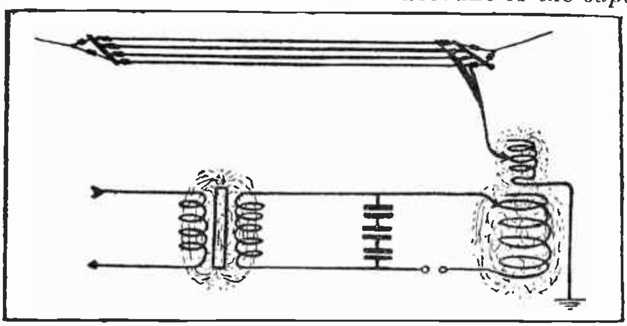


Fig. 118. High-Frequency Circuits of Spark Transmitter as Energized by Secondary of Power Transformer.

between the antenna and the ground. The antenna is frequently referred to as an "open circuit." It is not open, for an ammeter connected in series with it will indicate current flowing, when the transmitter is in operation. The invisible capacity forms the connecting link between the opposite ends of the wire composing the antenna system. The reason that alternating current can flow in a circuit having a condenser in series is that a charge is flowing *away* from one plate while another charge is accumulating in the opposite direction *on* the other plate, something like arranging two water pails so that one is always filling while the other one is emptying. On account of this, condensers are often used where it is desired to prevent a direct current from passing and to permit an alternating current to flow.

168. *The capacity of a condenser,* where other conditions remain fixed, depends upon its *size,* and the *pressure created* due to the difference in permeability of the conductor and dielectric, or in other words, ***capacity depends upon the surface area of the plates and the strength and thickness of the dielectric. The unit of capacity is the farad. One farad is that capacity which will produce a back pressure of one volt when the charge is one coulomb.*** This means that a difference of potential of one volt is also produced between the plates of the condenser. For convenience in measuring capacity the farad is divided into units of one millionth of a farad, or *microfarads.* These are also subdivided into millionths, or *micromicrofarads.*

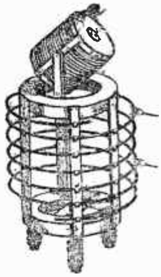


Fig. 119. Helix Type of Oscillation Transformer.

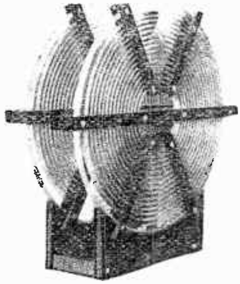


Fig. 120. Flat Type of Oscillation Transformer.

The centimeter of capacity is also used, where exceedingly accurate measurements are desired.

One mfd., or μf. = one microfarad = .000001 farad.

One mmfd., or $\mu\mu$f. = one micromicrofarad = .000000000001 farad.

One cm. f. = 1.11 microfarads = .00000000000111 farad.

The latter is sometimes referred to as the C. G. S. unit of capacity, meaning one centimeter-gram-second.

Capacities of fixed condensers used in transmitting apparatus generally range from about .001 to .1 mfd. One farad is so great a capacity that is is not used in actual practice. Where changes of capacity are desired in transmitters, two or more fixed condensers are frequently arranged so that they may be thrown in parallel, or out of the circuit by a switching device. Variable air-dielectric condensers may be obtained ranging from .00025 mfd. up to .005 mfd. Those customarily used in tuning circuits of receiving apparatus are usually of .00025, .00035 or .0005 mfd.

169. The ability of the dielectric to allow the electrostatic field to permeate through it affects the capacity of the condenser, and this is called the *dielectric constant,* which is understood to signify the *ratio of the capacity of the condenser using a given substance for a dielectric to the capacity of the same condenser with air for a dielectric.* Air has a dielectric constant of 1: glass a dielectric constant of 4 to 10: mica a dielectric constant of 4 to 8, etc.

Capacity is increased with an increase in the insulating property of the dielectric.

Capacity varies with the dielectric material, and the distance between the plates. It is increased when the plates are brought closer together, but if placed too near together, the current will break down the dielectric to jump from one plate to the other.

Table of Dielectric Constants.
(From U. S. Signal Corps Pamphlet No. 40.)

Substances	Values of dielectric constant
Air	1.0
Glass	4 to 10
Mica	4 to 8
Hard rubber	2 to 4
Paraffin	2 to 3
Paper, dry	1.5 to 3.0
Paper (treated as used in cables)	2.5 to 4.0
Porcelain, unglazed	5 to 7
Sulphur	3.0 to 4.2
Marble	9 to 12
Shellac	3.0 to 3.7
Beeswax	3.2
Silk	4.6
Celluloid	7 to 10
Wood, maple, dry	3.0 to 4.5
Wood, oak, dry	3.0 to 6.0
Molded insulating material, shellac base	4 to 7
Molded insulating material, phenolic base ("bakelite")	5.0 to 7.5
Vulcanized fibre	5 to 8
Castor oil	4.7
Transformer oil	2.5
Water, distilled	81.0
Cottonseed oil	3.1

Capacity may be defined as that property of a condenser, or a circuit, which enables it to hold a charge of electricity in electrostatic form. The capacity for holding an electrostatic charge is equal to the quantity divided by the pressure, or

$$C = \frac{Q}{E}$$

$$\text{Then } Q = C\,E, \text{ and } E = \frac{Q}{C}$$

The power in watts required to charge a condenser is shown by the following equation, with C in microfarads, F representing the alternator frequency in cycles per second, and E the charging voltage at maximum.*

$$P = C \times 10^{-6} \times E^2 \times F$$

The capacity required for successful operation of a transmitting set of a certain power is determined as follows:

$$C \text{ mfd.} = \frac{2 \times 10^6 \times \text{Power in watts}}{\text{Charging frequency} \times \text{Charging voltage}^2}$$

170. The calculation of the capacity of condensers can only be approximate, on account of the fact that the entire circuit in which they are connected has some capacity. The turns of wire composing the inductance coil, with their insulation and the air between them, combine to produce a capacity effect which must be considered as a suppositional condenser having its modifying effect on the circuit in which it is placed. It is impossible to add pure inductance to a circuit on account of this. There may also be capacity effects between the condenser and adjacent parts of the apparatus in which it is connected. *The capacity changes with the frequency of the charging current.* The higher the frequency of the charging current, the smaller the charge of electricity that can be stored in the condenser between the alternations of the charging current, hence a lowered effective capacity. This change under varying charging frequencies is most noticeable in condensers having a solid dielectric, and is not appreciable in condensers having an air dielectric. The

* $10^6 = 1{,}000{,}000$ $\quad 10^{-6} = \frac{1}{1{,}000{,}000}$

charge which a condenser can hold is also affected by the *voltage of the charging current.* A certain amount of current at a certain voltage will cause a condenser of a certain capacity to reach a state of back pressure equal to the charging voltage, while if the charging voltage were raised, it might be possible to place a still greater charge into that particular condenser. A formula for calculating the capacity of a condenser, having two parallel plates of the same shape and size, which is given out by the United States Bureau of Standards, is as follows:

C = capacity in micromicrofarads.
K = dielectric constant.
S = surface area of one side of one plate in square centimeters.
T = thickness of dielectric in centimeters.

$$C = 0.0885 \frac{K\,S}{t}$$

(It is understood that K and S are multiplied, and .0885 is then multiplied by the result of dividing this sum by t.)

When a condenser is composed of several parallel circular plates, the following formula will determine its capacity, where

N = Number of plates.
S = surface area of one plate in centimeters, which is πr^2.
K = dielectric constant.
t = thickness of dielectric.

$$C = .0885\,K \frac{(N - 1)\,S}{t}$$

For instance, what is the capacity in micromicrofarads of a fixed condenser consisting of 43 circular plates, when each plate is 20 centimeters in diameter, and they are separated for a distance of 1 millimeter, with transformer oil used as a dielectric?

Answer.

$$C = .0885 \times 2.5 \times \frac{42 \times 314.16}{.1} = .22125 \times \frac{13194.72}{.1} =$$

$.22125 \times 13194.72 = 2919.331$ micromicrofarads, or .00291 microfarad.

A useful rule for determining the number of plates, or sheets, of dielectric to use in constructing a condenser of a desired capacity is as follows:

$$\text{Number of sheets dielectric} = \frac{t \times C \times 10^6}{.0885 \times K \times \text{area of one plate.}}$$

How many sheets of dielectric are necessary to make a condenser having a capacity of .0055 microfarads, when the sheets are 15×30 centimeters in area, and .29 centimeters thick, with a constant of 8?

Answer.

$$N = \frac{.29 \times .0055 \times 10^6}{.0885 \times 8 \times 15 \times 30} = \frac{1595}{318.6} = 5 \text{ sheets dielectric.}$$

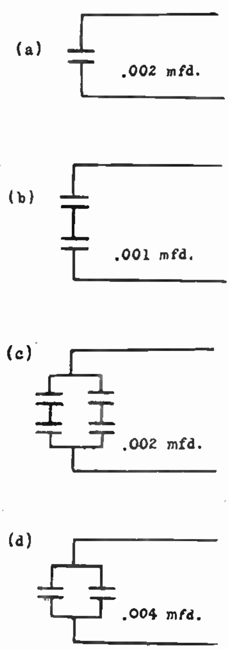


Fig. 121. Connections of Condensers.

171. As in other electrical devices, such as batteries and resistance coils, the manner of connecting condensers in the circuit affects their total capacity in that circuit. *When condensers are connected in parallel,* the total capacity of the group is equal to the *sum* of all of the capacities. When they are connected in *series,* the total capacity is *less than the capacity of one condenser.* The individual condensers remain of the same capacity, each is still capable of taking as much of a charge as when charged singly; but as *connecting them in series reduces the pressure,* the result is to *reduce* the *capacity* also. In certain cases this is done to protect condensers from breakdown where the voltage is higher than one condenser would be likely to stand. For instance, if we take a single condenser having a capacity of .002 mfds. and connect it as in (a) in figure 121, it will have an effective capacity of .002 mfds. If we connect two of equal capacity as in (d), the same illustration, the capacity will be

.004 mfds. However, if these condensers have not sufficient dielectric strength to stand the voltage which we wish to subject them to, we can still use them by sacrificing capacity. In (b) it will be seen that the same two condensers in series with each other have a capacity of only one-half that of one of them if connected as in (a). Therefore, to obtain the capacity of the one condenser, but with the protection given to them by series connections, we must use *four* condensers connected as in (c).

Connecting them in parallel is mechanically the same as connecting all of the plates on one side of the connection together, and all the plates on the other side together, and forming one condenser of greater surface area. Connecting them in series has the opposite effect, and may be thought of as having greatly increased the dielectric thickness, thus reducing the total capacity and causing the group to discharge sooner under a given charge, accelerating the frequency of the discharge current.

The manner in which the charge can go through a bank of condensers in series is often puzzling to the student. This can be explained by the electron theory. For instance, take the series group, b, in figure 121. Suppose that a positive charge is placed on the top plate of the upper condenser and a negative charge on the lower plate of the lower condenser. The positive charge consists of a *lack* of electrons, which has an attraction for the negative electrons in the material of the lower plate of the upper condenser, and also for the upper plate of the lower condenser. This results in an accumulation of negative electrons on the lower plate of the upper condenser, giving that plate a negative charge, and producing a condition of strain through the dielectric. As the negative electrons were moved away from the upper plate of the lower condenser, both by the attraction of the positive charge at the upper side of the bank and by the repelling force of the negative charge at the lower side of the bank, the upper plate of the lower condenser becomes positive, having a lack of negative electrons. This phenomenon takes place in reversed direction, when the direction of charging is reversed.

FORMULAE FOR CAPACITY OF BATTERIES OF CONDENSERS IN PARALLEL AND IN SERIES.

With condensers of like capacity, say three having a capacity of .002 mfds. each, designated as C_1, C_2 and C_3, if connected in parallel,

$$C = C_1 + C_2 + C_3 = .006 \text{ mfds.}$$

The same condensers as above, connected in series, would be

$$C = \frac{\text{capacity of one jar}}{\text{number of jars}} = \frac{.002}{3} = .00066 \text{ mfds.}$$

With condensers having different capacities, say one of .003 mfds., one of .004 mfds., and one of .006 mfds., when connected in parallel,

$$C = .003 + .004 + .006 = .013 \text{ mfds.}$$

With the same condensers as above connected in series, it is necessary to find the common denominator, and proceed with the problem as follows:

$C_1 = .003$ mfds.
$C_2 = .004$ mfds.
$C_3 = .006$ mfds.

$$C = \frac{1}{\frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_3}} = \frac{1}{\frac{1}{.003} + \frac{1}{.004} + \frac{1}{.006}} =$$

$$\frac{1}{\frac{4}{.012} + \frac{3}{.012} + \frac{2}{.012}} = \frac{1}{\frac{9}{.012}}$$

$$1 \times \frac{.012}{9} = .0013 \text{ mfds.}$$

172. With condensers and the high-frequency condenser discharge, we cross the dividing line between that which is usually thought of as "general electricity" and electricity which is more strictly radio. Returning to the electron theory of the performance of condensers, this assumes that

each atom of matter is composed of a number of positive units and an equal number of negative electrons maintained at equilibrium by electrical forces, and that when an atom loses one or more negative electrons it becomes positive, and when it gains more than its normal number of electrons it becomes negative. Kimball's *College Physics* states that "in insulators, if electric force is applied, there is a certain *yielding* or displacement of the electrons, if the force is increased the electrons are displaced more, but there is no continuous flow as in a conductor, and as soon as the external force is removed they spring back to their original positions, behaving as shot would if embedded in a mass of rubber. The displacement is only through a small distance and is opposed by the internal electric forces between the positive and negative elementary charges in the dielectric which urge all the electrons back toward their original unstrained positions." The *United States Signal Corps Pamphlet No. 40* gives us the following on the same subject: "In a perfect insulating material a steady (direct) current cannot flow. If an electromotive force is applied between two points of an insulator, a momentary flow of current takes place which soon ceases. This is due to the elastic reaction of the insulator. When considering the existence of electric strain or displacement in an insulating material, we do not think of this displacement as being due to the actual displacement of matter, on which the charge is carried from one plate to another in the substance. It is rather as if, in each molecule, a positive charge is moved to one end and a negative charge to the other. Then with all the positive charges pointing in one direction, the effect is that a certain change has been transmitted clear across the dielectric. An illustration may aid in making this idea clearer. In a dense crowd of people a sudden push or shove on one person will be sent through from person to person. Energy is transmitted, yet no single person has passed all the way across."

PROBLEMS

1. What capacity would you use in the condenser circuit of a 2-K. W. 500-cycle spark transmitter if the voltage of the power transformer secondary at maximum of each alternation is 17,000 volts?

Answer. .014 mfd.

2. What power would be reqnired to fully charge a condenser of .034 mfd. capacity at 500 cycles and 17,000 maximum voltage?

Answer. 4.9 K. W.

3. Given condensers of .005, .006, .01 and .015 mfd. capacity:

(a) What would their capacity in parallel be?
Answer. .036 mfd.

(b) What would be their capacity in series?
Answer. .0019 mfd.

CHAPTER 18

Oscillating Current

Oscillatory Discharge of a Condenser — Spark Discharge — Frequency — Antenna Coupling of Spark Transmitters—Radiation Field

173. The current discharged from a condenser will always be oscillatory, if provided with a suitable circuit. The charging current, for practical purposes, may be either alternating or pulsating current. As the voltage of the current is stepped up by the power transformer, the frequency is stepped up by a condenser, or a battery of condensers. The oscillatory discharge of the condenser increases the number of cycles many thousand times. Increasing the potential of the charging current does not affect the frequency of the discharge, for while there is a greater counter emf. generated, there is also added power furnished for doing the work. Likewise a decrease in the power of the charge does not lower the oscillation frequency of the discharge, on account of the corresponding decrease in the counter emf. to be overcome, so that the relation between the capacity and inductance will still be the same. The frequency of an alternating current depends upon the characteristics of the *force* which causes the alternations, namely, the mechanical arrangement of the field poles, and the number of revolutions per second. These *force* the alternations to take place at a certain period. They are forced alternations, no matter how rapid they may be. On the other hand, the oscillatory discharge of a condenser is not caused to occillate at a forced period. These are considered *free* oscillations. Lieutenant Stone, in his *Elements of Radio Telegraphy,* makes this clear in the following way: "With free oscillations, we may consider that a certain charge is given to a circuit which is converted into energy in *motion.* The circuit is not *driven* into oscillation, but is *allowed* to oscillate. The oscillations of a pendulum which is drawn to one side and then released are free oscillations, the frequency of the pendulum swings being determined solely by the length of the pendulum. But if the pendulum were grasped by the hand and made to swing according to the swings of the hand, its oscillations would be forced oscillations."

174. The oscillatory discharge of a condenser is probably the nearest approach to a successful imitation of one of the

great forces of nature that has yet been achieved by man. The state of charge between the plates of a condenser, just preceding discharge, is apparently identical with the state of strain between the clouds and the earth preceding a flash of lightning; and by many tests the lightning, when captured, as for instance on a lightning rod, has been proved to be oscillatory. Dr. Steinmetz, in 1922, succeeded in a laboratory production of "lightning" to the extent of causing it to "strike" a log and shatter it exactly as the natural lightning splits a tree. In Kimball's *College Physics* we find that *"Franklin obtained electric charges by means of a kite as a thunder-storm was approaching. The kite was provided with metal points. To the lower end of the kite cord was fastened a metal key to which was attached a silk cord which was held in the hand and acted as an insulator. Sparks were obtained from the key and leyden jars were charged, and the familiar phenomena of electric charges were observed.* The oscillatory discharge was examined by Fedderson in 1863 by means of a rapidly rotating mirror. Seen in this way, each discharge showed as a *group of sparks* at regular intervals, and rapidly dying out. When the discharge takes place through a sheet of glass it is pulverized at the point of discharge. When trees are struck by lightning they are apt to be splintered, large slivers being flung violently sidewise. A little gunpowder placed between the ends of two wires through which an oscillatory discharge is sent will usually be scattered unless the discharge is retarded by causing it to pass through a wet string or other poor conductor, in which case the powder may be ignited."

175. The brilliant spark of the Tesla coil, illustrated in figure 112, is formed by the gradually dying out oscillations of the condenser discharge. If one strikes a guitar string, the string vibrates, and the vibrations gradually die out. The condenser circuit vibrates in a somewhat similar manner, at a very much greater speed, under the electrical influence of the condenser discharge. When several thousand oscillations move from the condenser, along the wire and across the spark gap, through the inductance coil, rocking back and forth between the opposite plates of the condenser, the circuit is vibrating under the influence of a succession of oscillation trains, each train having its separate existence. and each following the other in rapid succession. There will be one complete separate oscillation train for each complete

discharge of the condenser. And as there are as many condenser charges as there are alternations in the charging current it can be seen that the *oscillation train frequency* will be just twice the frequency of the charging current.

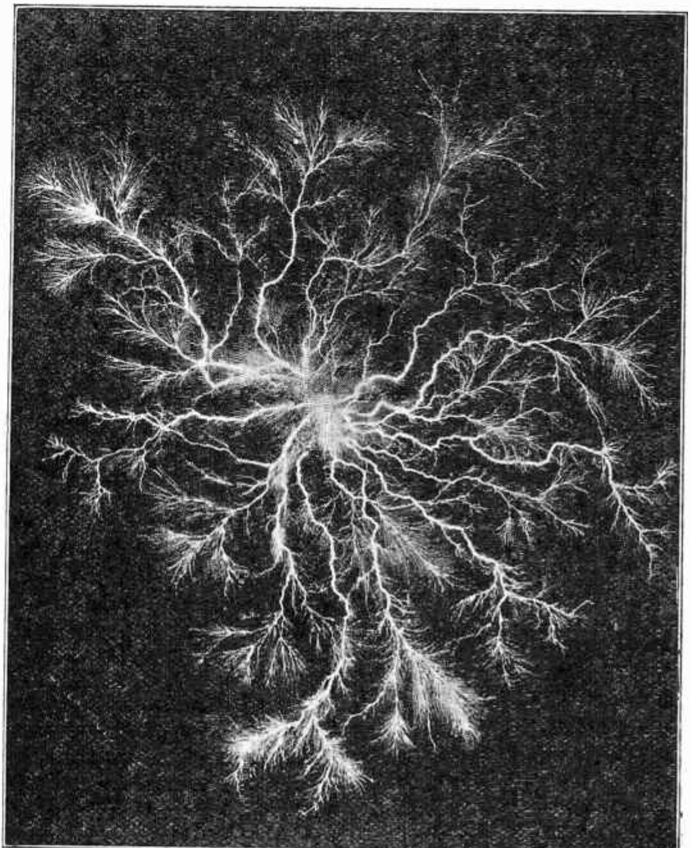


Fig. 122. An Electrograph, or Photograph of a Cross-Section of a Condenser Discharge Across a Spark Gap, with the Electrodes Twelve Inches Apart.*

This is understood to be the usual spark frequency with the majority of "spark" sets; and a transmitter adjusted so that there is exactly one spark discharge for every alternation

* This remarkable photograph was made by the Cullen Calvert Photo Company, of Washington, D. C., and presented by them to the author.

is said to have a *spark frequency* which is in *synchronism* with the charging current. However, the condenser may be caused to discharge at a different instant than the peak of the alternations of the charging current, under which conditions the condenser circuit is said to be out of resonance, or out of phase, with the alternator circuit. If the voltage applied to the condenser is increased, there may be a break down of the spark oftener than the alternator frequency. Also, if the charging voltage is suddenly reduced, there may be a *lag* of the spark discharge. This can be observed by noting the change in the *tone* of the spark as the generator field resistance is varied. The spark, appearing to be one long spark, lasting as long as the transmitting key is pressed, is made up of a succession of the oscillation trains.

176. The *frequency* of the *oscillations* is determined solely by the amount of *inductance and capacity* in the circuit. *Adding* either capacity or inductance, or both, *decreases the oscillation frequency;* and *subtracting* capacity, or inductance, or both, *increases the frequency.* The total charge of the condenser in the circuit depends upon its capacity and the pressure back of the charge; and the discharge period depends upon the capacity and the inductance in the circuit. *More time is required to discharge a condenser having large capacity than one of smaller capacity; and more time is required to cause a certain amount of current to flow through a circuit having a large amount of inductance than in a circuit of less inductance.* Therefore, connecting condensers in the circuit in any one of the ways illustrated in figure 121 will affect the frequency exactly as it increases or decreases capacity. *Condensers in parallel increase capacity, hence decrease frequency. Condensers in series decrease capacity, hence increase frequency. Increasing inductance has a retarding effect in the circuit, and decreases frequency. Decreasing inductance has an accelerating effect on the circuit, and increases frequency.* The last four statements may be considered as the four cornerstones of radio communication.

177. When the oscillations caused by each successive spark discharge are allowed to take place around the circuit consisting of the condensers, inductance coil, and spark gap, these oscillations are then conveyed by induction to any circuit which may be coupled to it. When the antenna is

thus coupled to the condenser circuit, the oscillations will repeat themselves in the antenna circuit, provided the antenna circuit is tuned to have about the same oscillation period, and we have the fundamental circuit of the old-time spark transmitter.

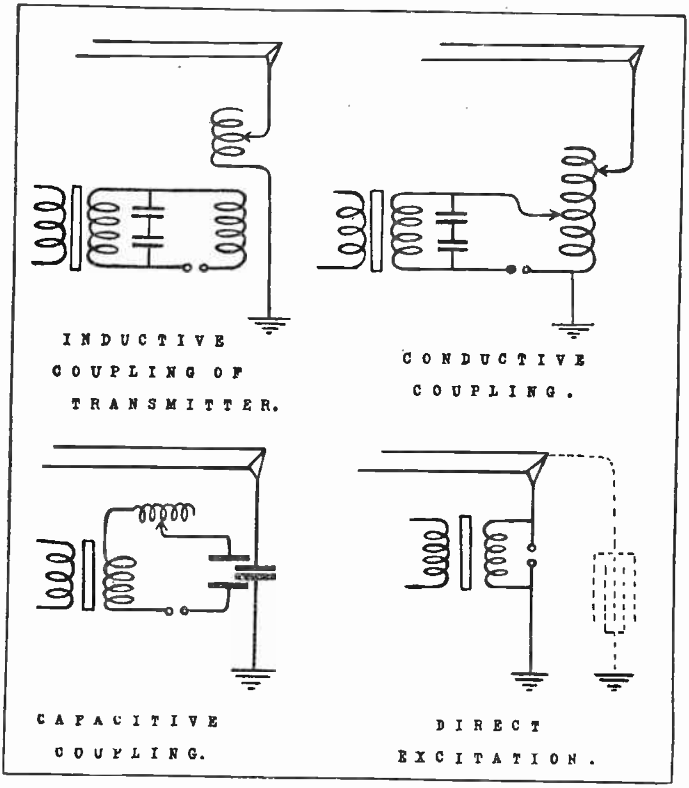


Fig. 123. Some Methods of Conveying Spark-Circuit Oscillations to the Antenna.

If this condition of resonance is obtained, the frequency of the antenna circuit will be the same as the condenser-spark-gap circuit, and electric waves of this frequency will then be radiated from the antenna in long and short groups of wave trains, corresponding to key pressures of long and short duration. The capacitive coupling in figure 123 illustrates electrostatic induction, in which the electrostatic field of the first condenser conveys impulses to the antenna condenser. In the direct excitation method the antenna capacity functions both in producing and radiating oscillations, and messages may be conveyed to receiving stations within range which are also tuned to resonance with the transmitter.

Electric waves can only be emitted from the antenna and used for communication when the antenna is energized by current of a *high frequency*. Around the wires of a circuit energized with a low-frequency current there is practically no *radiation field*, and the only method by which it conveys energy to another circuit is by induction. This is known as an *induction field*. The condition which is favorable for radiating electric waves to great distances through space is an electrostatic and electromagnetic field of great intensity and extremely high frequency of vibration surrounding the transmitting antenna. This gives a *penetrating* quality to the vibrations, and then the electric waves will travel.

There are several ways, besides the spark-gap method, of producing oscillating current and a high-frequency radiation field. In fact, there are many people who appear to believe that, although still used to some extent on sea-going vessels, the spark type of radio transmitter will eventually be completely replaced by continuous wave apparatus. "Time will tell." The spark type of radiation has some advantages for marine communication, and it is quite possible that it may be retained as an auxiliary to be used in case of emergencies. However, the fundamental rules stated in paragraph 176 apply to both types of apparatus: the oscillations, when produced by vacuum tubes, are conveyed to the antenna by induction; and all of the power machinery used with the spark set is required for the later types of apparatus. Continuous-wave transmitters are treated in chapters 31, 34 and 35.

CHAPTER 19

Capacity Reactance

Back Pressure of Condenser Charge—Impedence—Resonant Frequency—Power Factor—Series Resonance and Parallel Resonance—Resonance Curves

178. With capacity added to a circuit, we find that we have a new factor to consider, that is *capacity reactance.* The *back pressure* of the condenser charge, against the current producing the charge, has a retarding effect upon that current and must be included in the total impedence. If the *frequency* of the current passing through an *inductance coil* is *increased,* the *inductive reactance increases accordingly.* If the frequency of a current used for *charging a condenser* is *increased,* the *capacity of the condenser is decreased* and the capacity reactance decreases accordingly. It can then be seen that the reactive effect of inductance and capacity are exactly opposite.

179. In chapter 11 it was shown that the impedence in a circuit was equal to $\sqrt{R^2 + X^2}$. It was understood that X meant the total reactance, or, if marked with a small L, it signified the inductive reactance. With capacity reactance present, it is necessary in calculations to always signify by an L or a C which kind of reactance is referred to. In calculating the total impedence of a circuit having inductance and capacity, we subtract the smaller value of reactance from the greater in order to determine the total reactance.

$$Z = \sqrt{R^2 + (X_L - X_c)^2}$$

For instance, how much current flows in a circuit having a metallic resistance of 20 ohms, an inductive reactance of 25 ohms, and a capacity reactance of 10 ohms, when the impressed E. M. F. is 500 volts? Answer:

$$Z = \sqrt{20^2 + (25 - 10)^2} =$$

$$\sqrt{20^2 + 15^2} =$$

$$\sqrt{400 + 225} =$$

$$\sqrt{625} = 25 \text{ ohms impedence.}$$

$$\text{Then } I = \frac{E}{Z} = \frac{500}{25} = 20 \text{ amperes.}$$

180. It can be seen that capacity and inductance have certain effects upon the *frequency* of the current, and certain effects upon the *quantity* of current flowing in the circuit. With extremely high-frequency oscillating currents, the capacity reactance is small and the inductive reactance large. In such circuits the metallic resistance is usually small compared to the reactance. Unless accurately balanced, or tuned to resonance, high-frequency circuits will have an exceedingly small amount of current flowing in them. However, if the capacity and inductance are arranged in such a way that they neutralize each other, which is quite practical, the actual effective reactance may be reduced to about zero. This is possible because these two reactances are opposite, or in such a direction as to offset each other, and this effect will be most marked at some one frequency. This particular frequency at which the reactance can be reduced to zero is known as the resonance frequency of the circuit. At this frequency the impedence will be equal to only the resistance, and the most current will flow. Capacity reactance is in inverse ratio to both capacity and frequency, and current is increased when either of these is increased. With X_c representing capacity reactance in ohms, and C capacity in farads,

$$X_c = \frac{1}{2\pi \quad F \quad C}$$

For instance: a condenser having a capacity of 1 mfd. is placed in a 60-cycle circuit. Its reactance is

$$\frac{1}{2 \times 3.1416 \times 60 \times .000001} = \frac{1}{.000377} = 2652.5 \text{ ohms.}$$

If this condenser is connected in a radio-frequency circuit of 500,000 cycles per second, its reactance will be .318 ohm. Or, if a condenser of 25 mfd. is placed in the 60-cycle circuit, the capacity reactance will be 106.38 ohms.

The capacity reactance may also be determined with a voltmeter and ammeter. Capacity reactance is equal to the quotient of the effective voltage of the charging current divided by the effective current.

In a resonant circuit, in which the capacity reactance and the inductive reactance balance, they are as reciprocals,

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

Then the frequency is equal to

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

$$\text{and } X = \sqrt{\frac{L}{C}}$$

These facts can be proved by experiment. If a curve be plotted, on which is indicated the current in a resonant circuit, and various frequencies, an ammeter will indicate unmistakably the particular adjustment at which resonance exists. At this particular adjustment the increase in current will be pronounced, and above and below the frequency which produced this phenomenon the current will rapidly decrease.

181. In low-frequency circuits the *power factor* is noticeably affected by the state of resonance of the circuit. *Inductive reactance causes the current to lag behind the voltage, and decreases the power. Capacity causes the current to lead,* and increases the power of the circuit. In low frequency circuits a condenser is sometimes inserted to overcome the lagging effect of inductive reactance. It is possible by this method to greatly improve the power factor.

182. The effect of connecting condensers in series or in parallel is vastly different. In figure 124 is shown a simple series resonance, with capacity and inductance in series in an oscillatory circuit. The capacity may consist of one condenser or of several in series or in parallel with each other, so long as the total capacity is connected in series with the

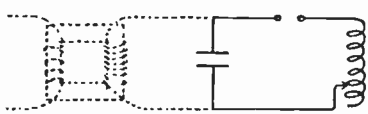


Fig. 124. Series Resonant Circuit.

inductance coil. This is the high-frequency circuit of a "spark" transmitter. On account of the high impedence of the secondary of the power transformer, when this circuit is used in the transmitter, the oscillatory discharge does not pass through that part of the circuit. In practice, after the condenser circuit of a transmitter has been installed, with the approximate capacity necessary to produce a certain desired frequency, the condensers remain fixed, and such changes as are required to change the natural period of the circuit are made by varying the connections to the inductance coil. Adding or subtracting inductance will increase or decrease the oscillating period of the circuit. When the condenser circuit is tuned to the required frequency, the antenna circuit may be coupled to it, and tuned to the same frequency, by observing the readings of an ammeter con-

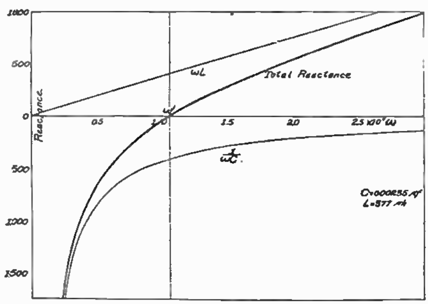


Fig. 125. Resonance Curve Showing Reactance in Series-Tuned Circuit. (From U. S. Bureau of Standards.)

nected in series in the antenna circuit. When the latter circuit has been tuned to resonance with the condenser circuit, the ammeter will clearly indicate this condition by showing the greatest current flowing, which indicates that the reactance has been reduced to minimum in that circuit. Series resonance circuits are employed in many types of radio transmitters, receivers, wavemeters, etc.

183. When a condenser and inductance coil are connected in parallel in a circuit, as in figure 126, a different effect is produced from that described above. The E. M. F. is divided between the condenser and the coil, which divides their reactances according to the impressed frequency. When the impressed frequency is high, the inductive reactance will predominate; and if it is lowered, the capacity reactance will

predominate. The current in these two branches flows in opposite directions, so that the total effective current in the rest of the circuit may be practically zero, although there is

Fig. 126. Parallel Resonance.

an alternating E. M. F. For this reason parallel resonance is used for *suppressing* currents of certain frequencies, especially in certain types of apparatus employing vacuum tubes. Arrangements of parallel resonance are known as "trap circuits," "wave traps," "filter circuits," etc. The parallel arrangement will oppose a current of only one frequency, and will not prevent the passing of other frequencies through the circuit.

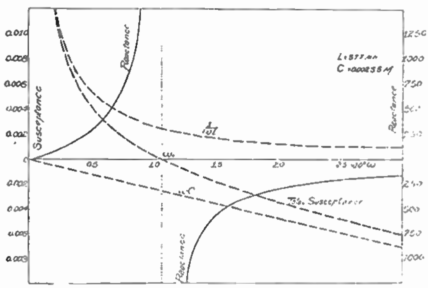


Fig. 127. Reactance Curve of Parallel Resonance.
(U. S. Bureau of Standards.)

Series resonance is used where *maximum current* is desired at resonance, and parallel resonance where *minimum current* is desired at resonance.

184. As can be understood, upon considering the relationship between the primary oscillatory circuit of a transmitter and the antenna circuit, the tuning of the former circuit is fundamental in wave length control. The natural period and resonance of this circuit, and the resonance of the antenna circuit, determine the general chacteristics of the radiated waves which are emitted from the antenna and sent out to be copied by one or more receiving stations.

CHAPTER 20

Electric Waves

The Ether—Effect of Radiated Waves—Dr. Mahlon Loomis's Theory of Electric Waves in 1865—Early Work of Hertz and Maxwell—Table of Frequencies of Electric Waves—Reflection, Refraction and Diffraction of Electric Waves—Corpuscular and Quantum Theory of Electric Waves and Light—Wave Length

185. There is probably no more absorbing topic before the scientific world than that of electric waves. The ablest minds are busy with research on the subject. Many of the standard text books on physics state that electric waves are radiated through the "luminiferous ether," that medium which it has been supposed existed between the planets, and in containers from which the air had been pumped. We have been told that electric waves could pass through stone walls, etc., because they did not depend upon the air, but upon the *ether* for their propagation. This theory appears to be, figuratively speaking, "on its last legs." Just how we shall replace it remains to be seen. We cannot conceive a state of nothingness, and with the time-honored theory of the ether discarded, what shall we call that which we must still believe to exist between the planets and within a vacuum?

186. It has been established beyond doubt that electric waves do not advance forward on the air which we breathe; and the manner in which electric waves may be radiated from a transmitting antenna and caused to reproduce signals in a receiving station, where a receiving antenna "picks up" the vibrations, proves their electro-magnetic nature. The exact nature of the medium through which these waves travel is still open to discussion. In paragraph 3 there was quoted an extract from a speech in Congress in Washington, D. C., in 1872, wherein Mr. Conger described the theory of electric wave propagation which had been propounded to him by Dr. Mahlon Loomis in 1869. Dr Loomis stated that he believed that the atmosphere surrounding the earth was charged with electrical energy, that the earth's "upper strata" of atmosphere was a "great electric sea," and that he could easily cause *"a disturbance in the electrical equilibrium of the atmosphere,"* and that these *"pulsations"* would cause *"electrical vibrations, or waves, to pass as upon the surface of some quiet lake one wave circlet follows another from the point of disturbance to the remotest shores, so that*

from any other mountain top upon the globe another conductor which shall pierce this plane and receive the impressed vibration may be connected to an indicator, which will mark the length and duration of such vibration, and indicate by any agreed system of notation, convertible into human language, the messages of the operator at the point of first disturbance." There is every reason to believe that this theory came to the mind of Dr. Loomis prior to the year 1865, because at that time he was actually putting it into use in his famous experiments in the Blue Ridge Mountains. He claimed also that *"the earth is like the inside of a leyden jar, and the upper strata of the atmosphere like the outside of a leyden jar, and the intervening air like the glass of a leyden jar,"* which seems to indicate that he must have had some notion of the oscillatory discharge of a leyden jar, and of the capacity between the antenna and the ground, as they are related to the propagation of electric waves, even though he could not have possessed all of the apparatus considered essential for radio communication at the present time. The written records of his experiments, and of his sublime theory, have accumulated the dust of two generations, only recently to be brought out into the light and examined with a greater understanding.*

187. Text-books published in the meantime have agreed in stating that electric waves were discovered by Heinrich Hertz, in Karlsruhe, Germany, in 1884 or 1885; and the description of the performance of these waves is identical with the description given out by Dr. Loomis, in that they *"pass as upon the surface of some quiet lake one wave circlet follows another from the point of disturbance to the remotest shore."* This description is usually accompanied by a photograph of some *ripples upon the surface of a "quiet lake."* Preceding Hertz, in Europe, several eminent persons were also approaching the same conclusion regarding electric waves. Outstanding among these was James Clerk Maxwell, professor of physics in the University of Edinburg, Scotland. About 1867 Professor Maxwell, by an amazing system of mathematical calculations, evolved the theory that light must consist of countable vibrations, or waves;

*See *Radio News*, November, 1922, for the story of Dr. Mahlon Loomis, including a copy of a remarkable lecture delivered by him regarding the use of atmospheric electricity. Also *Radio Broadcast*, December, 1925, article by Robert H. Marriott, First President of Institute of Radio Engineers.

that there must be other vibrations which we cannot see; that these waves are of an electro-magnetic character; and that the speed of light and the invisible electro-magnetic waves is 186,173 miles per second, or approximately 300,000,000 meters per second.* In other words, that those phenomena which we discern as *light, heat and color* are nothing but *electric waves* of different frequencies. The object which we see in a particular color is actually vibrating at a fixed rate, and these vibrations set up corresponding trains of vibrations or waves, which are radiated, and which our senses record as a certain light or color.

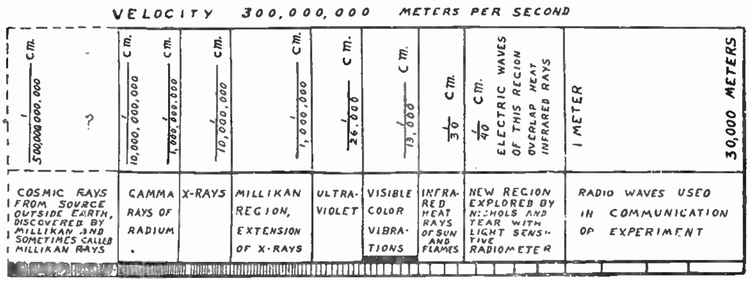


Fig. 128. Complete Spectrum of Electric Waves.

188. In Hertz's famous experiments he proved that electric waves are radiated from an oscillatory discharge across a spark gap. He used an oscillator and a resonator, as shown in figure 129. With the resonator held in his hand he moved about his laboratory, and within certain distances from the oscillator he found that a small spark would jump across the space between the gap in the resonator, or *wire hoop*. The latter was tuned to be in resonance with the frequency of the waves radiated from the oscillator, that is, it was of just the right size to respond to these vibrations. In this way Hertz verified the opinion of Maxwell, and, for probably the first time in history, determined the *wave length* of the electric waves which he was using. Hertz also established the close relation between those waves and light waves. The electric waves responded to several experiments that had been performed with light. He found that when electric waves radiated from his oscillator were directed against a metal mirror connected to the resonator that there would be a spark across the gap of the resonator, but that if he held a piece of sheet *iron* between the oscillator

*In November, 1926, Prof. Michelson, who, fifty years before, had calculated the velocity of light to be 186,213 miles per second, announced that further research had proved it to be 186,173 miles per second.

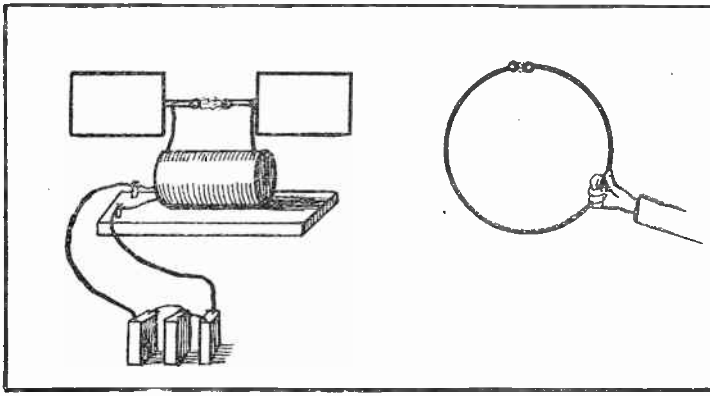


Fig. 129. Hertz Oscillator and Resonator.

and the resonator there would be no spark. This he considered as a *shadow.* He believed that the iron absorbed the waves, on account of its being *opaque* to them as it was to light. He also claimed that the electric waves have each a *north* and a *south polarity,* which causes them to proceed in a given direction by the laws of attraction and repulsion.

189. Electric waves may be reflected at an angle to correspond to the angle of their progress toward the reflector,

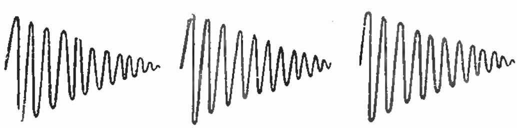


Fig. 130. A Group of Damped-Wave Trains.

and *refracted* and *diffracted.* In figure 131 a parabolic metal mirror is connected so as to act as a reflector of extremely short waves produced by an induction coil. The waves radiated from this device are *polarized,* or sent out in a parallel *beam,* much as the rays of light are reflected from a searchlight.

If a similar parabolic reflector be placed in the plane of the first one, and connected to an appropriate detector of electric waves, the reception of these waves can be proved. If a screen composed of parallel wires be placed in the path of these polarized electric waves, as at A, figure 131, the waves are detected in the receiver as before. However, if the parallel wires be placed parallel with the plane of the waves, as at B, they are intercepted, and do not reach the receiver. With the wires parallel to the waves, current is induced in the screen, and the screen has a polarizing effect on the waves. If the wires are spaced closely, the screen acts like a solid sheet of metal, completely reflecting the waves. If the screen be placed at an angle, as at C, the waves are broken up into two components at right angles to each other. The component which is in a plane parallel with the wires of the screen passes through the screen, and the receiver responds. If the receiver is placed at an angle to correspond with this component, the volume of the received signals will be increased. A B indicates the original plane of the transmitted waves.

At D is illustrated the manner in which electric waves may be reflected by a sheet of metal, when the waves are projected towards it at an angle.

At E is shown how electric waves can be diffracted by passing them through a prism attached to a screen, which prevents them from passing to the receiver otherwise. In this case the loudest response in the receiver will be as indicated at R, instead of in direct line from T.

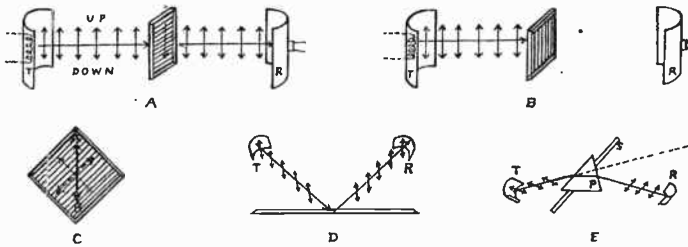


Fig. 131. Polarization and Screening of Electric Waves.

190. Regarding *diffraction* of electric waves, we quote from Robinson's *Manual of Radiotelegraphy and Telephony*, "When waves meet a body in their path (for instance, when the comparatively long waves used in wireless telegraphy impinge on a high island or mountain range) at the points where the wave front cuts the extreme width of the island and along the crest or summit, new centers of disturbance are created, which radiate some of the wave energy to points behind the island or mountain. It has the effect of bending the waves around the object. This action of waves is called *diffraction*. In amount it depends on the

wave length. From the new centers of disturbance waves are sent out, which interfere with each other, not being propagated in the same directions. The result is that for a distance, depending on the *width* and *height of the obstacle* and on the *wave length*, a *shadow* exists beyond it. At a distance depending on the size of the rock and the wave length, the zones of interference disappear, the regular waves from the two sides of the rock unite, and there is no evidence of its existence at points beyond, though it has decreased the *total strength* of the waves. For the above reasons, *high land between two wireless telegraph stations has the effect of decreasing the strength of signals at each station, and if close to either station, may entirely prevent that station from receiving.* The effects of reflection and diffraction on waves passing over irregular country are very pronounced. The effects of reflection, refraction and absorption in the atmosphere are equally pronounced, the qualities of the atmosphere varying greatly from day to day and between day and night."

191. Steinmetz said, in his lectures on relativity, published in 1923, *"The hypothesis of the ether has been disproved and abandoned. There is no such thing as the ether, and light and wireless waves are not wave motions of the ether. The beam of light and the electro-magnetic wave are therefore periodic alternations of the electro-magnetic energy field in space, and the differences are merely those due to differences of frequency."*

The magnetic lines of force surrounding the earth can easily be conceived of as lending themselves to all the requirements for wave propagation. This magnetic field offers a continuous and elastic medium, and has a tendency to return to its original position. This is proven, on a smaller scale, in the distorted field of a dynamo. So we have a state of strain in the medium, when it is moved out of its normal position by the disturbing influence, and kinetic energy when it returns to its normal position.

Superseding the electromagnetic idea of radiation and its medium, comes the *corpuscular theory* advanced by Sir William Bragg. This appears to have been developed from suggestions previously offered by Planck and Einstein. In a general way this states that a *source of light* must be *vibrating*. Heat applied in various ways sets electrons composing the material into oscillation; from the force of this oscillating, some of the free electrons are thrown off from the object; these travel through space, maintaining their independent identity, still vibrating; and that a material object upon which they may eventually strike has conveyed to it this particular period of vibration, setting its own free electrons into vibration. Quoting from Bragg, "It is as if one dropped a plank into the sea from a height of 100 feet, and found that the spreading ripple was able, after traveling 1,000 miles and becoming infinitesimal in comparison to its original moment, to act upon a wooden ship in such a way that a plank of that ship flew out of its place to a height of 100 feet."

It is believed that radiant energy consists of electrons which are radiated as a *group,* having a certain quantity of combined energy, and absorbed at some point in their path as a group. This *group,* which is supposed to have retained its identity from radiation to absorption, is called a *"quantum,"* which also means the *unit* or the *corpuscle.* And each quantum has a certain *momentum.*

Arthur F. Compton, then of the Washington University, has contributed still another advancement in the theory. This has been named the "Compton effect." What he observed was a different radiation set up by the encounters between the quantum originally radiated and free electrons. When a quantum collides with a free electron, some of its energy and momentum are imparted to the free electron, the residues of each going to form a new quantum. This has less energy and momentum than the original quantum, hence a lower frequency of vibration, and it is deflected in a direction oblique from the direction of the original quantum.*

In other words, it appears that space may be filled with countless quantums of electrical energy, continually darting about in all directions, and colliding with each other as they are propelled in one direction or another. And perhaps it is true that *this* is the *mysterious medium* that was at first given the name of the "ether."

In the diary of Dr. Mahlon Loomis, dated December, 1868, we find the following: "At this date I look at the matter thus: Far above the surface of the earth is one vast ocean

*See the *Bell Technical Journal,* April, 1925, article by Karl K. Darrow on "Some Contemporary Advances in Physics."

of electricity. That if this ocean be penetrated above all local disturbances it will yield a never failing current—is, in fact, as exhaustless as the watery ocean of the earth. And I further think that if this ocean or reservoir of electricity be penetrated at two distant points, the common electrical element thus penetrated will act as a conducting medium and consequently form one half of a circuit of which the earth may be made to form the other half, thus

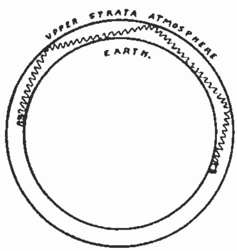


Fig. 132a. Supposed Path of Reflection of Electric Waves.

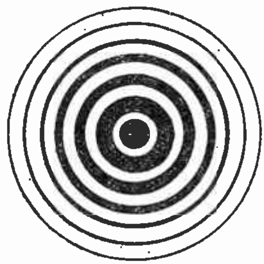


Fig. 132b. Conventional Symbol of Electric Waves Radiated from the Point of Electrical Disturbance "as Ripples Follow on a Quiet Lake from a Point into which a Stone Has Been Cast."

dispensing with all wires and cables for conveying messages from point to point. I believe that this same ocean or electrical element may be so utilized as to answer all purposes of heat, light and mechanical force or motion. And still further, inasmuch as the earth together with the other planets are held in their respective places by some power or agent, I believe that power or agent to be *electricity,* and that being bound and connected as they are by this one element common and continuous to them all, a direct communication to and from these planets will sooner or later be had with as great facility as we now have from city to city." A somewhat similar theory regarding the existence of a *conducting* layer at the upper rarified limit of the atmosphere was later advanced by a British physicist named Oliver Heaviside, and this is now frequently referred to as the "Heaviside layer." It is this which is believed to cause the electric waves to be *reflected,* as indicated in figure 132a, and which appears to absorb some of their energy, constituting what is known as "fading" of the signals at regular intervals during transmission, especially at night and on short wave lengths.

Whatever one's belief regarding the medium through which they travel, or their similarity to light, the fact that we are radiating electric waves, receiving them, controlling and measuring them, is indisputable. Practically the only limitation to the distance to which we can send them is the limit of the energy placed behind them. On September 22, 1918, for the first time, electric waves were sent *completely around the world.* This was accomplished as a test between the Marconi high-powered vacuum-tube transmitting station at Carnarvon, Wales, and Wahroonga, Australia, at 3:15 a. m. At that time, the medium covering the *entire surface of the earth* must have been vibrating under the influence of this disturbance.

192. A *wave* must be thought of as a *motion* or *disturbance,* which passes on the surface of, or through the mass of, a given medium, and as *not necessarily implying a movement forward of any part of the medium itself.* One wave length is generally considered to be the distance from trough to trough. One electric wave might be represented graphically on a horizontal drawing of several sine curves, as the distance between any two peaks of successive negative alternations. It can be seen how, when the frequency of the vibrations causing the disturbance which starts the waves on their way, and the velocity at which they travel, are known, it is possible to determine the actual length of the individual waves. The regulation of the wave lengths which he uses is a part of the work of the practical radio operator. He is required to keep within the wave lengths allotted to his particular station by the government under which he is working. By the use of various bands of wave lengths, a certain control is achieved, and the *interference* between stations greatly reduced. However, with the increased number of transmitting stations in operation, this has become a serious problem, and means for improving methods of transmission, so that stations will tune much more sharply than they were at first required to, are being developed.

193. If the velocity at which electric waves travel is 300,000,000 meters per second, obviously the wave length in meters is this number divided by the frequency, or number of separate waves per second. In formulae dealing with

wave length, the greek letter lambda is employed for wave length.

$$\lambda m = \frac{\text{velocity}}{\text{frequency}}$$

For instance, if the frequency is 100,000, the wave length is 3,000 meters. Fundamentally, the wave length of the usual type of radio apparatus, whether used for transmitting or receiving, is the result of the inductance and capacity of the apparatus, which determine the frequency at which it can vibrate.

CHAPTER 21

Resonance and Coupling

Effect of Coupling Upon Radiated Waves—Requirements for Controlling Radiated Waves—Principle of Resonance in Energy Transfer by Electric Waves—Pure and Impure Wave—Sharp and Broad Wave—Plain Aerial Transmitter—Formula for Mutual Inductance

194. There is nothing gained by making more or less elaborate preparations for propelling electric waves into space in long and short groups of wave trains, or in continuous waves, which may carry either the message of the key or the voice, unless they *can be received* by the party for whom they are intended. In order to receive them, the receiver must be within range of the distance that the transmitter is capable of sending; the operator must have an apparatus constructed to receive whichever kind of wave, damped or undamped, the transmitter is prepared to send; he must have his receiving apparatus tuned to approximately the same wave length as that of the transmitter; if the message is in the telegraphic code he must, of course, be able to read this, and he must not be interfered with by having to hear all of the transmitters within range at the same time.

195. In the early days of commercial radio work, there was great confusion, both as to code and lengths and types of waves that interfered with each other. At an international convention of representative radio men, held in London, in 1912, the code known as the international Morse, or Continental code, was adopted to be used by all radio operators, for all regular public service. This covers all the languages that use the Roman alphabet—English, German, French, Spanish, etc. Such languages as Chinese, Japanese, Greek, Russian, etc., requiring another code. At this convention there were also many other important international laws and regulations agreed upon, consisting of what might be called the *traffic laws of* radio communication; and in order to avoid trouble, it is necessary for the practical radio operator to be thoroughly familiar with these rules. A number of these laws and regulations are in reference to the use of certain wave lengths, and the purity and damping of the waves.

196. The requirements for controlling the waves sent are based on the golden rule, the idea being to *overcome interference* as much as possible. If it is possible for two people to communicate with each other in such a way as to avoid

interfering with two other people, who also wish to communicate, why not do it that way? This is possible by *tuning the transmitters and receivers to different wave lengths,* and by coupling the transmitting circuits so as to permit the radiation of a pure non-interfering wave. Also, there is the right to use a kind of wave that will interrupt everybody, and be heard everywhere, within range. This is the kind of a wave that one is entitled to use for a distress call, S O S, and at no other time. It corresponds to a scream for help. You don't care whom you bother, if you are being killed and are calling for assistance, and everyone will excuse you for making yourself heard. However, if everybody went around continually carrying on conversation as if they were screaming for help, no one could hear anyone else.

197. The difference between a broad interfering wave and a sharp non-interefering wave corresponds to the difference in coupling. Electrical coupling consists of joining two circuits together. The motor and generator are coupled together. Each separate circuit in the radio transmitter is, in a way, coupled to the adjoining circuit. However, in speaking of the radio transmitter, coupling is understood to refer to the *joining of the closed oscillation circuit to the antenna circuit and the resonance between these two circuits.* Resonance is not necessarily confined to circuits which are coupled together. In a circuit having inductance and capacity these two factors must be adjusted to balance, or neutralize each other and this condition is also called a state of resonance. A resonant circuit is one in which the capacity reactance and the inductive reactance exactly neutralize for any particular impressed frequency. Resonance between two coupled circuits consists of a value of capacity and inductance in each circuit so balanced that the two circuits have the *same natural period,* or *wave length.*

198. The condition of resonance between two circuits is believed to have been discovered in 1880 by Sir Oliver Lodge. He found that electro-magnetic induction takes place between two leyden jars when they are connected in two circuits having the same period. He charged a leyden jar with a battery, and provided a spark gap for its discharge, as in figure 133. He discovered, by accident we believe, that another leyden jar also provided with a spark gap, but not charged from the battery, if placed in the vicinity of the charged condenser, would behave exactly as the charged con-

denser, *provided that the length of the wire and the capacity of the condensers were the same.* By arranging the second circuit so that he could slide a piece of wire or strip of metal

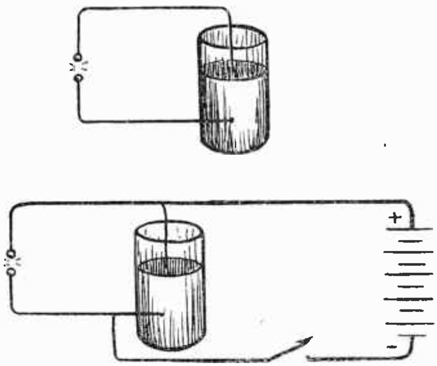


Fig. 133. Sir Oliver Lodge's Resonance Experiment.

back and forth on it, he found that he could vary the energy of the spark discharge from the second condenser, and that the brightest spark took place when he had the second circuit tuned exactly to resonance with the first circuit, which proved that *at resonance there is the greatest transfer of energy.* This is the foundation of the principle of resonance. Two high-frequency circuits must be tuned to resonance with each other to give the best results. When the antenna circuit is coupled to the primary oscillatory circuit of a radio transmitter, these two circuits must be in resonance. When a receiving station "listens in" it will get the loudest signals when it is in resonance with the transmitting station. It may not have the same *amount* of inductance and capacity, but it has its inductance and capacity of such values that the *period* is the same.

199. When the secondary of the spark-set oscillation transformer is placed in inductive relation to the primary the oscillations of the condenser circuit are conveyed to the antenna by induction; and the oscillations of the antenna circuit, when a plain spark gap is used, react upon the primary, and the radiated wave is affected by this *mutual induction* between the two circuits. When the secondary of the transformer is placed very close to the primary coil, in what is called *close coupling,* the mutual induction between the two coils is high, and the oscillations induced into the sec-

ondary re-induce a new set of lines of force back into the primary, then re-induce still another set back into the secondary, and so on until the mutual induction gradually dies out with the damping of the oscillations set up by the condenser discharge. The result of this mutual induction is that two waves are radiated from the antenna, the main wave and the lesser one due to *mutual induction.* The second wave becomes a part of the wave train, and travels along at variance with it, producing an *"impure wave,"* which it is difficult to tune out at the receiving station. This is one of the objections to this type of transmitting apparatus.

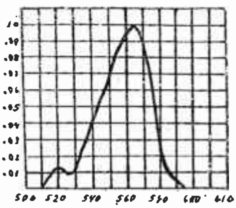


Fig. 134. Graph of Impure Wave with Second Wave within the Law. (Horizontal numbers represent wave length and vertical numbers current.)

200. As the secondary of the oscillation transformer is drawn away from the primary, the antenna oscillates more nearly at its own period, and this is called *loose coupling.* With this adjustment the second wave from the primary circuit becomes much weaker in volume. When it is possible to transfer energy to the aerial at the point of coupling where the second wave has completely disappeared an absolutely *pure wave* will be produced, confined exactly to one wave length. However, this can not always be done, because at this point, with certain types of transmitters, using certain types of spark gaps, *no energy* is transferred to the aerial. Therefore the government made a rule for spark transmitters, permitting the radiation of a wave train in which a somewhat subdued second wave existed. This applies to such of the older installations as may still remain in use. The *law defines a pure wave as one radiated from a coupled pair of circuits that are oscillating at the same period, hence producing a wave train confined to waves of one length—or "from coupled oscillating circuits radiating waves in which the lesser wave shall not be more than one-tenth the amplitude of the greater wave."*

By definition, *a sharp wave is a wave that requires accurate tuning of the receiver to be detected, and which can be easily tuned out when not desired by the receiver.*

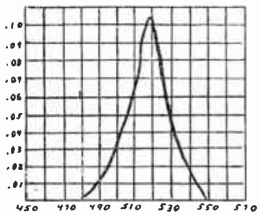


Fig. 135. Graph of a Pure Wave, which is also a Sharp Wave.

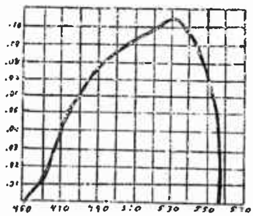


Fig. 136. Graph of a Broad Wave.

A broad wave is one that can be detected by every receiving apparatus within range, at every tuning, or over a wide range of tunings, and which causes interference because it can not be tuned out. The use of this type of wave is prohibited by law, except for distress calls. It is due to too close coupling, and, in some cases, to the type of spark gap used.

201. Antennæ may be excited into vibration in several ways, and the methods used each have their particular effect upon the radiated waves. *Inductive coupling* is the only form of coupling for spark transmitters now permitted, except in emergency. This is sometimes called magnetic coupling. Conductive and capacitive coupling have been used to some extent (see figure 123). *Conductive coupling* consists of connecting the antenna directly to the inductance coil of the condenser circuit, making this coil serve as both primary and secondary of the oscillation transformer, or as an auto transformer. By variable connections, it is possible to obtain fairly good coupling with this method, but never loose coupling, and the tuning is difficult and inconvenient compared with the inductive type of oscillation transformer. In capacitive coupling there is no oscillation transformer but a simple tuning inductance in the closed circuit. This arrangement can never be tuned sharply.

It is possible to transmit messages without artificial condensers, using simply a *"plain aerial transmitter,"* with a spark gap directly in series in the antenna circuit, and utilizing the capacity between the antenna and the ground. This is known as the *direct excitation* method. It was used by Dr. Mahlon Loomis, and is still recommended to practical operators on board vessels as an emergency method, in case of irreparable damage to their regular apparatus. The spark will discharge across the gap, and the current in the antenna will be oscillating. It is like substituting the antenna circuit for the condenser circuit, and radiating the electric wave directly from the condenser, or oscillatory circuit, except that the antenna is a better radiator of the oscillations than an artificial condenser. Naturally, this type of a transmitter is difficult to tune, and sends a broad interfering wave. On account of the additional resistance in the antenna circuit, when the spark gap is arranged in this manner, there is an extremely high decrement in the radiated waves.

202. The coupling of two circuits which are conductively coupled may be increased by increasing the inductance of the coil which is common to both circuits. Coupling of circuits inductively coupled may be increased by decreasing the distance between the two coils, or by adding turns of wire in either coil. The effect of the mutual inductance, produced by the mutual induction back and forth between the two coils, has a distinct effect upon the reactance of each circuit, and hence upon the current in each circuit. This mutual effect, or *degree* of coupling, is called the *coefficient of coupling,* which is expressed as follows:

$$K = \frac{X_M}{\sqrt{X_c \quad X_L}}$$

where K represents the coefficient of coupling, in percent. and K_M the mutual reactance of the two circuits working upon each other.

This reduces to

$$K = \frac{M}{\sqrt{L_1 \quad L_2}}$$

where M represents mutual inductance, and L_1 and L_2 the inductance in the primary and secondary circuits, in any like units of inductance. The coupling is regarded as loose or close according to the value of K. The greatest possible value that J can have being 1, the nearer to unity is this number the closer is the coupling.

CHAPTER 22

Wave Lengths and Tuning

Fundamental Wave Length of Antenna—Inductance and Capacity in Relation to Wave Length—Short-Wave Condenser—Measuring Wave Length—Wavemeters—Resonance Curve—Kilocycle

203. Every antenna has what is called its natural period or *fundamental wave length.* This is the wave length of the wave radiated from the antenna without any added inductance or capacity. Adding either will change the wave length by increasing or decreasing the frequency. The purity and sharpness of the radiated waves are affected by the coupling; and this may also indirectly have some effect upon the wave length. The principles of resonance and tuning apply equally to modern vacuum-tube transmitters which are now common on land and are gradually being installed on seagoing vessels, and to the older spark transmitters which could never be tuned to as narrow a band of wave lengths.

When tuning the antenna circuit to resonance with the primary circuit, and in adjusting the coupling, some indicating device is used to show the *adjustment at which there is the greatest transfer of energy from the primary to the secondary circuit.* For this purpose a hot-wire ammeter is usually placed in series in the antenna circuit. As it shows the actual current in the antenna circuit, this also is an approximate indication of the transmitting range of the apparatus. The hot-wire ammeter contains a piece of resistance wire, and the *effective value* of the high frequency current passing through it is indicated on the calibrated dial, by the expansion and contraction of the resistance wire under the influence of the heat produced by the current. Fairly accurate results may be secured by inserting a lamp of the right amount of resistance in place of the ammeter, determining the best adjustment for resonance and coupling by the brilliancy of the lamp. Hot-wire ammeters are rather delicate devices and frequently burn out, in which case practical operators find the lamp a convenient substitute.

204. As the frequency of the oscillating current, and the length of the radiated waves, depend on the inductance and capacity of the oscillating circuits, it can be seen that by varying the latter we can vary the wave lengths. By varying the connections to the primary coil of the transmitting oscillation transformer any wave length within the possibilities of the apparatus can be obtained. An additional *inductance coil* is generally included in the antenna circuit for the purpose of obtaining wave lengths longer than are possible with the antenna and secondary of the oscillation transformer. The wave length is shortened by the addition of a condenser, or battery of condensers, in series with the antenna. These are known as *short-wave condensers.* They are usually connected in the circuit with a switch shunted around them so that they can be placed in or out of the circuit at will by opening or closing the switch. With the short-wave condenser in series in the antenna circuit, we have the capacity between the antenna and ground in series with the condenser, and the effect is *exactly the same* as that produced when we connect any two condensers in series with each other (see paragraphs 171 and 176). *By decreasing the capacity, we increase the frequency, and hence shorten the wave length.* Of course, when either the tuning inductance or short-wave condenser is used, resonance must be preserved between the antenna and condenser circuits by keeping them both tuned to the same period.

205. The process of measuring the wave length of the two oscillation circuits and tuning them to resonance is sometimes called calibration. In the installation of a transmitter the wave length of each circuit may be taken separately and then the two circuits adjusted together, or it is possible to calibrate the two circuits by setting the primary of the oscillation transformer for the desired wave length, and then simply tuning the antenna circuit to resonance with this. To obtain measurements of the circuits, a *wavemeter* is indispensable. A wavemeter is an instrument consisting of a coil of wire, a variable condenser, and some kind of an indicating device. The condenser plates turn on a shaft, connected to which is a pointer giving readings on a dial. In some of the older types of wavemeters this dial was cali-

brated to read in frequencies, after which it was necessary to determine the wave length by the formula given at the end of chapter 20. Wavemeters now are generally made to give readings in wave lengths or in kilocycles. The dials are made by calibrating the meter to known wave lengths from a standard apparatus, and marking these lengths on the dial for different settings of the condenser, with coils of different inductance plugged into the wavemeter. The device for determining the transfer of energy between the wavemeter and the apparatus being tested, when the former is placed in inductive relation to the latter, may be a crystal detector and receiving telephones; or it may be a milliwattmeter with a small step-down transformer, a glow lamp, or a milliammeter, connected directly in series with the wavemeter circuit. The milliwattmeter or milliammeter are the most convenient to handle.

In figure 137, second diagram from top, the detector and phones are capacitively coupled to the tuning circuit, thus removing their resistance from the latter.

206. In taking the measurements, the wavemeter is placed a few feet from the transmitter, and a reading is made of the primary circuit. The antenna may then be forced to oscillate separately at its own natural period by direct excitation, using an induction coil and spark gap, or a buzzer may be connected directly in the antenna circuit, or inductively coupled to it. The buzzer, however, often proves rather feeble for this purpose. The two circuits are adjusted to about the same wave length, and then coupled, after which a wavemeter reading is taken of the radiated wave. Or, the transmitter may be tuned by simply disconnecting the antenna from the ground, and after calibrating the primary circuit to the desired wave length, the antenna circuit is reconnected to the transmitter, and the antenna inductance varied until the maximum transfer of energy is indicated in the antenna ammeter, with the loosest coupling that will permit this transfer of energy. The two circuits are then said to be in resonance, or tuned to resonance. The point where the greatest transfer of energy takes place, after the two circuits have been tuned to the same period, is at that adjustment of the oscillation transformer which places the two coils in such a position that there is the greatest percentage of cutting through of their lines of force. This is not in close coupling, where they are too close together to

permit the turns of wire composing the secondary of the oscillation transformer to receive the greatest number of lines of force, nor at the point where, with a spark set, a pure wave would be procured, because at this adjustment there can be practically no radiation. It is at a point between these two, and this is only found by experimental tuning of the apparatus. If it is desired to calibrate the transmitter for a particular wave length, as is usually the case, the wavemeter is set with the pointer at this wave length and the transmitter is adjusted until the greatest resonance is obtained between the transmitter and the wavemeter, as shown by the indicating device. A wavemeter equipped with a detector or other resonance indicating device is in reality a miniature receiving apparatus. When a wavemeter is equipped with a buzzer and a key or push-button for operating it, it is a small transmitting device; or, as it is sometimes called, a circuit driver. When this is inductively coupled to the antenna, and used as a source of oscillations a receiving set which is also inductively coupled to the antenna can be calibrated to the required wave lengths.

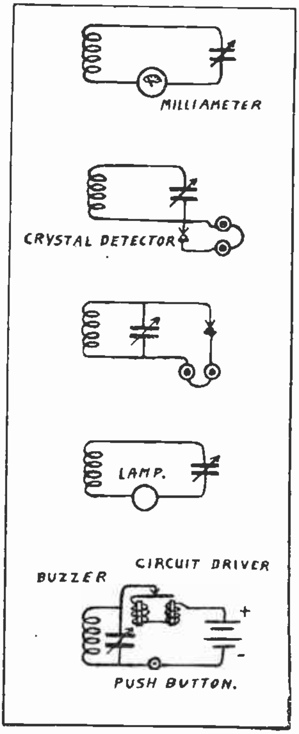


Fig. 137. Wavemeters.

207. For convenience in adjusting a transmitter, it is customary to make a *resonance curve* of the settings on the primary coil of the oscillation transformer at which certain wave lengths are procured. This is wave lengths plotted against settings on the coil. By plotting wave length against amplitude we can obtain a curve showing the character of the emitted waves.

208. If it is desired to change the wave length of a transmitter, the connections of both circuits must be changed so

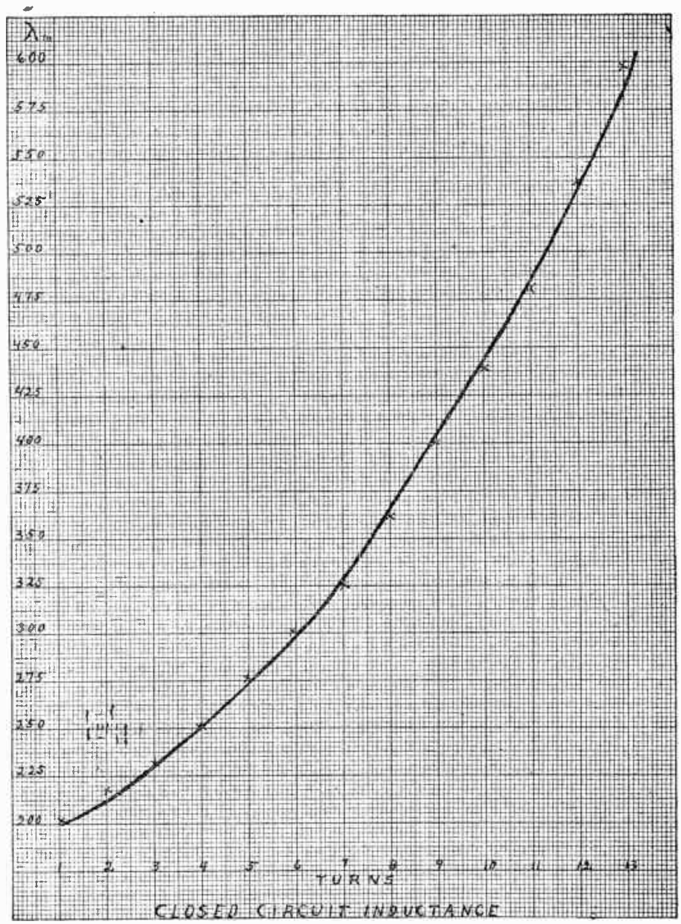


Fig. 138. Resonance Curve.

that they will still be in resonance with each other. Any change in either one, without a corresponding change in the other, will throw the apparatus out of resonance and cause a broad interfering wave. When the desired wave length has been procured markings are usually made on the inductance coil, indicating the spot at which the connection should be made for this particular wave length. Standard transmitters are built to conform to definite wave lengths, or with adjustments that can be varied to procure the wave lengths prescribed by law. After these have once been determined, the practical operator is seldom called upon to change the wave length of his transmitting apparatus.

209. The law requires that all radio transmitters installed on ships shall be able to send on the commercial wave lengths, as fixed by the Department of Commerce, and also on the wave length designated for radio compass work. These wave lengths have been changed from time to time, especially since the development of broadcasting stations, in attempts to reduce interference. Different foreign countries have different allotments of wave lengths, according to their own ideas of what is convenient; but the measurement of wave lengths in meters is international. In figure 139, with the short-wave condenser switch opened, and the tap on the loading coil at the point indicated by the dotted line, a short wave would be radiated, while with the switch closed and the inductance at the upper position on the coil, the wave length would be lengthened.

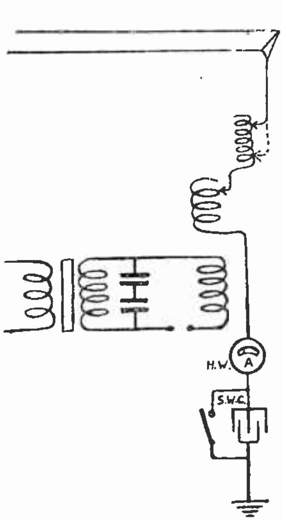


Fig. 139. Standard Arrangement for Varying the Wave Length of an Antenna System.

210. As shown in preceding paragraphs, $\lambda m = \frac{\text{velocity}}{\text{frequency}}$

Then, with a wavemeter, which will give an indication of the wave length, it is possible to determine the frequency of the oscillations by transposing this formula—

$$F = \frac{V}{\lambda m}$$

When the inductance and capacity of resonant circuits are known, the wave length can be determined by various formulæ. The United States Bureau of Standards gives out the following simple equation for approximate wave length, on which others are founded or to which they must eventually reduce. With L in microhenries and C in microfarads—

$$\lambda m = 1884 \sqrt{LC}$$

Standard tables have been made giving the wave lengths that will be obtained with different values of inductance and capacity and in practical work these are convenient for reference. A newer way of designating the frequency of the radiated waves was proposed at the National Radio Conference in Washington, in March, 1923. This is to use the frequency in *kilocycles*. For instance, if a transmitter is operating on a 300-meter wave length, there would be 1,000 kilocycles per second in the antenna circuit, or if operating on 600 meters, 500 kilocycles would be the frequency in thousands of cycles. To determine this, when the wave length is known, divide 300,000 by the wave length in meters. It is believed that the use of this term will overcome some of the confusion as to wave lengths, and assist in reducing interference. (See appendix for table showing wave lengths for various values of capacity and inductance, and for converting from wave length in meters to kilocycles.)

CHAPTER 23

Damping

Waves of Moderate and Excessive Damping—Cause of Damping—Logarithmic Decrement—Logarithms—Decremeter

211. Part one of this book deals with *damped waves* and fundamental principles. Part three treats of undamped, or continuous, waves. *Damped waves are waves of gradually diminishing amplitude,* and this refers to the waves composing each individual wave train set up by each condenser discharge across a spark gap. *Undamped waves* are waves which do not diminish in amplitude, or *have no damping.* These are the product of a different type of apparatus. Waves of *moderate damping* are waves which are damped out slowly, thus holding their volume for a comparatively long time, and producing a *long train* of waves, which will give a clear tone in the receiving telephones. Waves of *excessive damping* are waves composing a wave train which dies

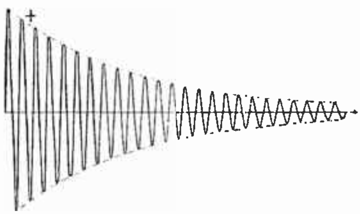


Fig. 140. Waves of Moderate Damping.

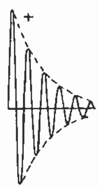


Fig. 141. Waves of Excessive Damping.

out too rapidly. They do not travel to a great distance, and are difficult to receive. There is one wave train for each spark-gap discharge, but as each wave dies out quickly, there is a longer space between the wave trains than with a feebly damped wave train, so that *less energy* is transmitted. These waves are produced by an oscillating circuit that is wasting its energy.

212. The damping of the waves composing each wave train radiated from the antenna depends upon the damping of the oscillations in the condenser and antenna circuit of the transmitter, principally upon the resistance in the condenser circuit. The total loss of energy is due to the metallic resistance of that circuit, which wastes a portion of the energy in heat,

by loss of energy at the spark gap, the type of gap used having some effect on the damping, and, to some extent, to escape of electricity by a brush discharge at the edge of the condensers. There is also a certain loss of energy in the condenser circuit by the transfer of energy to the antenna circuit. This is not considered as a waste. It is unavoidable. Also, the metallic resistance of the wires composing the condenser circuit is unavoidable. However, such things as brush discharge of condensers and excessive resistance in the gap can be overcome. Indirectly, the inductance of the circuit also has some effect upon the damping, as it contributes to the radio-frequency resistance. The smaller the inductance and the higher the frequency, the greater will be the damping.

213. The law, made regarding spark transmitter installations and applying to the old sets still remaining in use, requires that the damping shall be within certain limitations. The *maximum percentage of damping that is allowable is such that the logarithmic decrement does not exceed .1. The maximum decrement permitted was for many years .2, but the change to .1 was adopted by the Department of Commerce in 1925. The logarithmic decrement is the Naperian logarithm of the ratio of any wave to the following one in the same direction in a wave train having a constant ratio of damping. Its symbol is the Greek letter delta* (δ).

214. The following quotations from Slichter's *Mathematical Analysis* are not amiss: "The almost miraculous power of modern calculation is due, in large part, to the invention of logarithms, in the first quarter of the seventeenth century by a Scotchman, John Napier, Baron of Merchiston. This invention was founded on a very simple and obvious principle that had been quite overlooked by mathematicians for many generations. Napier's invention may be explained as follows: Let there be an arithmetical and geometrical progression which are to be associated together, as, for example, the following:

A.	0,	1,	2,	3,	4,	5,	6,	7,	8,	9,	10
G.	1,	2,	4,	8,	16,	32,	64,	128,	256,	512,	1024

Now the product of any two numbers of the second line may be found by adding the two numbers of the first progression above them, finding this sum in the first line, and finally taking the number lying under it. This latter number is the product sought. Thus, suppose the product of 8 by 32 is desired. Over these numbers of the second line stand the numbers 3 and 5, whose sum is 8. Under 8 is found 256, the product desired. Now since but a limited variety of numbers is offered in this table, it would be useless in the actual practice of multiplication, for the reason that the particular numbers whose product is desired would probably not be found in the second line. Napier proposed to insert any number of intermediate terms in each progression.

A.	.00	.25	.50	.75	1.00	1.25	1.50	1.75	2.00
G.	1.00	1.19	1.41	1.69	2.00	2.38	2.83	3.36	4.00

The correct position of the decimal point can be determined by inspection after the significant figures of the product have been obtained. Using the above table we find $2.38 \times 14.1 = 33.6$ (or, $2.38 \times 1.41 = 3.36$).

The above table, when properly extended, is a table of logarithms. As geometrical and arithmetical progression different from those given might have been used, the number of possible systems of logarithms is indefinitely great. The first column of figures contains the *logarithms* of the numbers that stand opposite them in the second column." The word logarithm is from two Greek words meaning "the number of the ratios." (See appendix.)

215. Regarding the application of logarithms to the ratio of damping in waves, Slichter says: "If a body vibrates in a medium like a gas or liquid, the amplitude of the swings are found to get smaller and smaller, or the motion slowly (or rapidly in some cases) dies out. In the case of a pendulum vibrating in oil, the rate of decay of the amplitude of the swings is rapid, but the ordinary rate of the decay of such vibrations in air is quite slow. The *ratio* between the lengths of the successive amplitudes of vibration is called the *damping factor*, or the *modulus of decay*. The same fact is noted in case the vibrations are the torsional vibrations of a body suspended by a fine wire or thread. Thus a viscometer, an instrument used for determining the viscosity of lubricating oils, provides means for determining the rate of decay of the torsional vibration of a disk, or a circular cylinder suspended in the oil by a fine wire. The amplitude of the swing is in this case the angle through which the disc or cylinder turns, measured from the neutral position to the end of each swing. *In all such cases it is found that the loga-*

rithms of the successive amplitudes of the swings differ by a certain constant amount or, as it is said, the logarithmic decrement is constant."

216. A wave train having a *logarithmic decrement* of .2 will have 23 waves before it dies out. *The ratio of the amplitude of any given wave in this train to the wave following it* is approximately 1.2, and the logarithm of this ratio is .2.

The ratio of successive waves in a wave train having a logarithmic decrement of .1 is as 1.11 to 1. With some types of spark gaps the decrement may be less than this. However, it is possible to have the decrement so slight that the diminishing end of each wave train is overlapped by the full amplitude waves at the beginning of the next wave train. This is undesirable, as it produces a mushy tone in the receiver.

217. Measurement of the decrement is made by a wavemeter, or a decremeter, the latter being an especially calibrated wavemeter, equipped with additional dials calibrated to give the logarithms of the decrease in amplitude of succeeding waves of various wave lengths. This is accomplished by having the logarithmic decrement reading dials connected by means of gears to the condenser shaft in such a manner that their movements are always in correct proportion. There are several decremeters on the market. One invented by Dr. Frederick Kolster, who was for several years head of the radio laboratory of the United States Bureau of Standards, and known as the Kolster decremeter, was adopted by the government for use in the army and navy, and is used by radio inspectors whose duty it is to inspect and report conditions in the radio room on board vessels.

218. For obtaining the decrement with an ordinary wavemeter, the milliwattmeter or milliammeter are usually employed for indicating resonance. The inductance coil of the wavemeter is placed in inductive relation to the circuit which is being measured, and the position and adjustment experimented with until maximum resonance has been obtained, as indicated by the milliwattmeter, or milliammeter, for the longer wave length employed by the transmitter. Several readings are then taken, on various wave lengths, in each case turning the condenser dial of the wavemeter to take readings off resonance, both above and below the resonant adjustment. The amount of decrease in current induced into the wavemeter, for off resonance positions, for each

wave length, indicates the decrease in amplitude of the oscillations, or radiated waves—in other words, the decrement. When these readings are marked off on cross-section paper, showing the current obtained for different wave lengths on resonance and off resonance, the ratio of damping may be determined. This also is a means of judging the general distribution of energy in the radiated wave, the sharpness and degree of purity of the waves, and the amount of interference that the transmitter is likely to cause. This is a rather tedious process, and the direct-reading decremeter is obviously much to be preferred for quick and accurate results.

219. As damping depends upon the resistance of the circuit, measurements of degrees of damping are indirectly measurements of the resistance of that circuit. Therefore, if the total resistance is known, this can be used in different ways for calculating the decrement of the circuit. One of the simplest of these formulæ is the following:

$$\delta = \pi R \sqrt{\frac{C}{L}}$$

with C in microfarads, and L in microhenries. (For exhaustive treatment of the subject of calculating the decrement, see *Circular of Bureau of Standards No. 74*.)

220. By determining the logarithmic decrement we can know the value and characteristics of the electric waves intercepted at the receiving station. If the decrement is high, the waves damping out quickly, the waves will be difficult to receive well, but at the same time may interfere with other receivers. If the wave is decidedly impure, having a secondary wave that is more than that prescribed as allowable by law, the result may be somewhat the same. On the other hand, if the waves have a low percentage of damping, giving long even trains of feebly damped waves, and if the waves are approximately pure they will tune in more sharply than highly damped waves and give a good volume of current in the receiving apparatus, with a clear strong note in the receiving telephones. However, the characteristics of damped waves are such that they can never be tuned in or out as sharply as continuous waves, and this is the reason that they have become unpopular since the advent of the broadcasting station.

CHAPTER 24

Spark Gaps

Early Spark Gaps—Requirements of Spark Gap—Effect of Quenched Gap on Radiated Waves—Rotary Gap—Amateur Rotary-Gap Transmitter

221. The first spark gaps were probably nothing more than the bare ends of two pieces of wire. As soon as attempts were made to cause sparks across the secondary of the induction coil, small balls were placed on these ends as a finish, and to increase the sparking surface. Small round rods of metal were also used for the same purpose. In the earliest forms of wireless telegraph apparatus the gap was located in the antenna circuit in the manner described in previous chapters as the "plain aerial" method of transmission. Difficulty with excessive damping, and heating, although the nature of the damping was probably not understood, led to constant attempts to improve the spark gap, and to many experiments with it in the way of location. The plain *straight spark gap* was discarded for commercial work many years ago. It had a tendency to form an arc whereby a part of the alternating current from the secondary of the step-up transformer failed to enter the condensers, but discharged directly across the gap, making operation impossible and damaging the spark electrodes. The arcing was over-

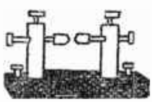


Fig. 142. Plain Straight Spark Gap.

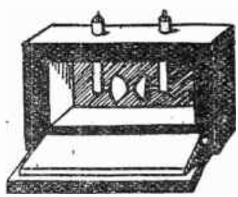


Fig. 143. Marconi Silence Box.

come by moving the electrodes farther apart, but this offered greater resistance and increased the damping. The plain gap makes considerable noise and, as this was objectionable in the radio operating room, different arrangements were tried to overcome this. One of them was that of enclosing the gap in a thick, soundproof box.

222. In order to get the best results from a transmitter employing a spark gap, there should be a low resistance against the flow of the high-frequency current when the condensers discharge across the gap, to permit the greatest possible transfer of energy into the antenna circuit, and also to reduce damping and the second wave to a minimum. On the other hand, it is desirable that the gap should offer sufficient resistance to the current to prevent the condenser from discharging until it has become charged. When a spark gap becomes heated its resistance is lowered, and the oscillations from the condenser discharge may continue after they have been greatly reduced in amplitude. *The ideal condition is a high resistance between condenser discharges, and a low resistance at the time of the discharge.* With the gap cooled in some manner there is a great improvement in the radiated waves. The heating of the air in the vicinity of the gap, or ionization, reduces the resistance, and destroys the dielectric properties of the air space between the gap electrodes. When plain gaps were enclosed in silence boxes, or in hard rubber or glass containers, as was done in some cases, it was necessary to exclude air from the gap chamber. The spark taking place in the air converts the oxygen and nitrogen of the air into oxide of nitrogen, which in turn produces a nitrous acid which deteroriates the gap electrodes. To overcome this, various gases were forced into the gap chamber, among them carbonic dioxide. Quicklime was also used to absorb the nitrous vapor.

223. An improvement over the above devices was the *quenched-spark gap,* placed on standard spark transmitters of the panel type installed on seagoing vessels. This consists of several circular or square discs placed about one-hundredth of an inch apart and held tightly in place by means of clamps at each end. The sparking surface is in the center of the disc, and around this is a raised ridge which fits with the ridge on the adjoining disc in such a manner that when clamped together the spaces between the sparking surfaces are airtight. Around these ridges are cooling flanges, and there are insulating washers between the ridges of the discs to prevent short circuiting of the gap. Sometimes the sparking surfaces are silver plated. The quenched gap is generally cooled by an air blast from a small electric fan equipped

with a trumpet-shaped tube which throws the air directly into the gap. The result of this arrangement of a number of spark gaps in series, with the cooling blast, is to *quench out the oscillations of the primary circuit rapidly.* This is not the same as a rapidly damped wave. It is simply stopped off short, so to speak, and the *antenna then continues to oscillate at its own natural period* until the wave train which has been started is completed, its length then depending upon the resistance of the antenna circuit. This prevents mutual induction in the way of the re-transfer of energy from the antenna circuit back into the primary condenser circuit. This *permits of the use of closer coupling than can be used with the straight gap, and a greater transfer of energy into the antenna circuit, without the objectionable second wave* during the portion of the radiated wave taking place after the oscillations of the primary have been quenched. On account of the sparking surfaces being enclosed in airtight spaces,

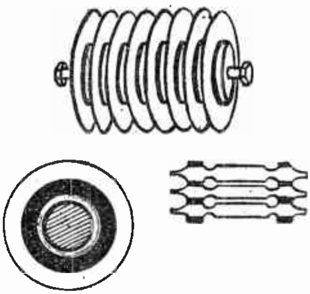


Fig. 144. Quenched-Spark Gap.

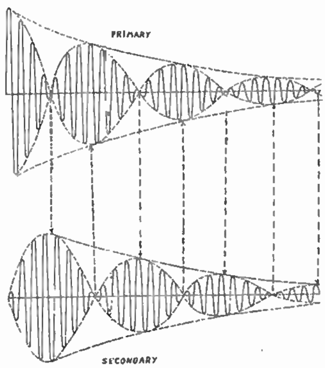


Fig. 145. Illustration of the Manner in which One Damped Wave Train from a Plain Spark Gap Sets up Oscillations in the Antenna Circuit and How These Reinduce Oscillations Back and Forth Between the Two Circuits. In Practice the Two Sets of Oscillations Overlap, Producing an Impure Wave.

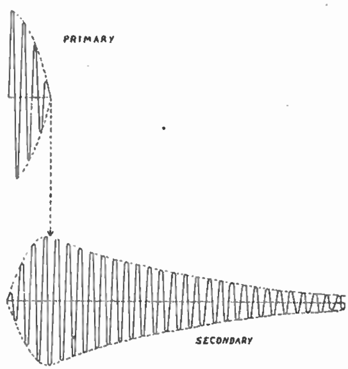


Fig. 146. Illustration of the Manner in which a Quenched-Spark Gap Stops the Mutual Induction Between the Primary and Secondary Circuits, Permitting the Radiation of a Pure Wave.

this gap makes only a very little noise in the operating room. It is possible to radiate waves of sufficient power to travel the desired distance without the use of extremely high voltages for charging the condensers. Connection to the gap is made with variable clips, thus permitting the use of as many of the electrode discs as desired. By varying the number of discs used the quality of the note can be varied somewhat, and tuned to get as clear a note as possible, which will be easier for the receiver to copy than a rough unmusical tone. When properly adjusted *a clear musical note* is obtained from the quenched gap. Transmitters using this type of gap have sometimes been referred to as *impulse* transmitters.

224. Still another type of gap is known as the *rotary gap.* This consists of a number of gap electrodes, arranged so that part of them are stationary, and the others rotated by a motor.

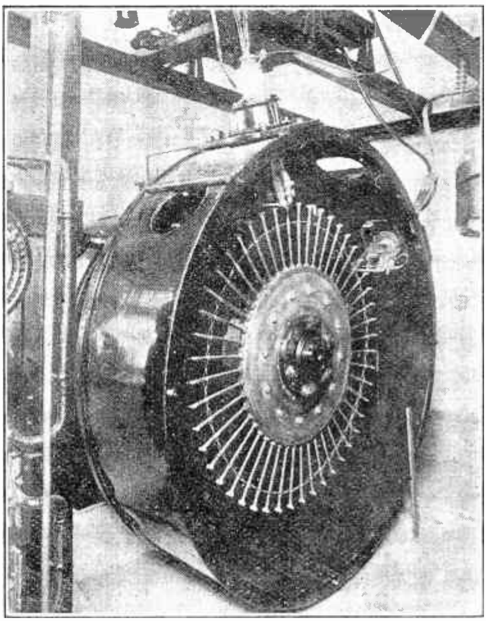


Fig. 147. The Old Synchronous Rotary Spark Gap, Which After Twelve Years of Service at NAA, was Discarded in Favor of Vacuum-Tube Apparatus. This Installation was Among the First of the High-Powered Stations.

As the rotating electrodes pass the stationary ones, there are two sparks in series. One advantage of this type of gap is that the rotating electrodes cool themselves, and if there is an arc formed it is immediately broken. The effect of this cooling of the electrodes is to cause the gap to immediately return to its original resistance after each successive discharge, so that it is practically a form of quenched gap, and reduces the mutual induction between the primary and secondary of the oscillation transformer in much the same manner as does the stationary quenched gap. When the rotary gap is used in connection with commercial radio transmitters it is usually adjusted to a synchronous relation with the alternating current of the power circuit. This is accomplished by mounting the gap on the end of the generator shaft and adjusting the electrodes, which are moveable around the frame, so that a spark occurs at the peak of each alternation of the current. This can be determined by experiment, and also by the mechanical alignment of the gap electrodes in their relation to the field poles of the alternator. The synchronous rotary gap gives a high, clear, musical note which is quite pleasant to copy, and is easily heard through interference. By having the sparks occur with each alternation, the relation between the condenser discharge and the *spark frequency* is the same as with the plain gap or the quenched gap. There is one discharge for each alternation, and the spark frequency, oscillation train frequency, and wave train frequency are twice that of the number of cycles in the power circuit. The synchronous rotary gap is more suited to the use of high power than the fixed quenched gap. The rotary gap may be operated by a *separate motor*. In this case it is extremely difficult to adjust it to spark in synchronism with the alternator frequency, so this is called a *non-synchronous rotary gap. The spark frequency then depends upon the number of electrodes and the speed of the driving motor.* Therefore, the condensers are forced to discharge exactly in unison with the *mechanically determined spark frequency*, regardless of their state of charge or of the charging frequency. There is then no relation between the frequency of the power circuit and that of the spark frequency. This gives a shrill note, the tone varying with the speed of the motor. It is also hard on the condensers. If the gap electrodes are a little too far apart, the condensers are forced to charge for a period which may be

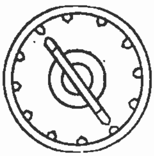


Fig. 148. Another Type of Rotary Gap.

longer than the normal charging period and are quite likely to break down under this treatment. However, with careful adjustment of the gap, and the use of a condenser with a good dielectric and, where advisable, the use of two or more condensers of large capacity in series with each other, this can be made to give satisfactory results. Before the low-powered vacuum-tube apparatus practically replaced spark sets for amateur transmitting some amateur operators were operating rotary-gap transmitting outfits successfully on an alternating-current city power line, thus doing away with the heavy and expensive motor-generator. By using a synchronous induction motor this separate gap

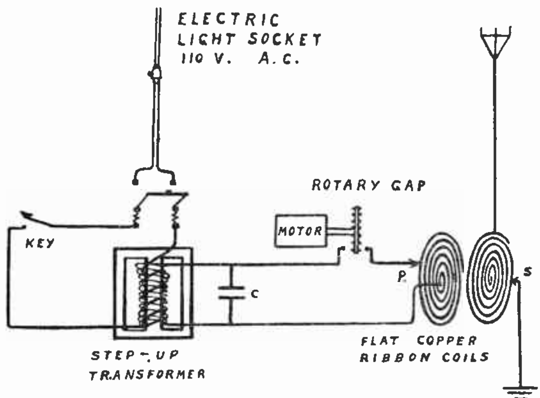


Fig. 149. Rotary Gap Transmitter Operated from Electric Light Socket.

was practically a synchronous gap when adjusted to spark with the alternations of the charging current. Of course, this would be difficult to accomplish in case of the supply being a polyphase current. As all forms of spark gaps produce *damped waves,* which are less penetrating in proportion to the power back of them than continuous waves, and which always must cause greater interference than continuous waves, various methods of generating the latter have been developed, and have replaced the "spark transmitter" in practically all *new* marine installations. However, the spark-gap type of apparatus is still found in operation on many seagoing vessels, and an understanding of it is essential to a commercial radio operator.

CHAPTER 25

Auxiliary Storage Batteries

Law Regarding Auxiliary Power Supply on Ships—Auxiliary Other Than Batteries—Chemistry of Lead Cell Battery—Chemistry of Edison Cell—Lamp Bank Resistance in Charging—Voltage and Current Capacity of Batteries—Diagram of Complete Spark Transmitter with Storage Battery Auxiliary Source of Power, Based on Principles Covered in Part One of This Book

225. On page 5, of the *Radio Communication Laws of the United States and the International Radiotelegraphic Convention*, we find the following: "Be it enacted by the Senate and the House of Representatives of the United States of America assembled—

"Section 1. That from and after October first, nineteen hundred and twelve, it shall be unlawful for any steamer of the United States or of any foreign country navigating the ocean or the Great Lakes and licensed to carry, or carrying, fifty or more persons, including passengers or crew, or both, to leave or attempt to leave any port of the United States, unless such steamer shall be equipped with an efficient apparatus for radio communication, in good working order, capable of transmitting and receiving messages over a distance of at least one hundred miles, day or night. An auxiliary power supply, independent of the vessel's main electric power plant, must be provided which will enable the sending set for at least four hours to send messages over a distance of at least one hundred miles, day or night, and efficient communication between the operator in the radio room and the bridge shall be maintained at all times."

226. Electric waves travel about three times the distance in the night that they do in the day time. For this reason, all laws regarding auxiliary equipment specify that the power must be sufficient to send the required distance in the *day time*.

An induction coil can be used in lieu of other apparatus for emergency transmission, but this requires storage batteries for power. Induction coil emergency transmitters are still being installed on small sea craft, which do not carry a sufficient number of persons to come under the requirements stated in the above paragraph. However, for vessels carrying fifty or more persons, this will not be passed by the government inspectors as an efficient auxiliary outfit; and storage batteries are called for. They must have a large enough capacity to be used in place of the ship's dynamo as a source of power for operating the regular transmitter, including the motor-generator. These batteries are kept in a properly protected place on the upper deck, where they will be available for operating the transmitter long after the lower part of the vessel, in case of accident, may be flooded, and the dynamo out of commission. This source of power must be kept in the best of working order at all times. Needless to say, these batteries have been the means of saving many lives at sea. In the navy a "motor buzzer" is sometimes used, in much the same manner as the induction coil.

227. Storage batteries, or more correctly, batteries of storage cells, produce direct current by the chemical process. They are the *secondary cells* referred to in paragraph 42, and are sometimes referred to as *accumulators*, this term being universally used in England. Storage cells may be given two general classifications, that of lead cells and nickel-iron cells. The latter are a comparatively recent development as compared to the lead cells. The first accumulator was made by placing two lead plates in a glass jar containing sulphuric acid solution. When the plates were connected with a galvanometer, no action was indicated. If, however, the cell had direct current from a primary cell sent through it for several hours, and was then connected to the galvanometer, the needle of the meter was deflected, indicating that current was flowing through the wire. In this process of "charging" the lead plate cell, the electrode nearest to the positive pole of the charging source was converted into lead dioxide, PBO_2, generally called lead peroxide by the manufacturers. When the accumulator is connected to an external circuit so as to discharge, the pole which was positive on charge becomes positive on discharge, so that current discharges from the cell in an opposite direction to the direction of charging. While the cell is discharging, electrolysis of the water liberates hydrogen on the positive plate. This unites with the oxygen of the lead dioxide, and produces water. The sulphuric acid in the electrolyte unites with the lead of the positive plate, and converts it into sulphate of lead, $PBSO_4$. The spongy lead of the negative plate is also attacked by the sulphuric acid and converted into lead sul-

phate. As this process continues, the specific gravity of the electrolyte falls, and the cell "runs down." It can be renewed again and again by reversing the chemical processes in it by sending a charge of electricity through it in the opposite direction. This drives the acid out of the plates, raising the specific gravity of the electrolyte, and the negative plate is restored to its original condition of pure soft lead, and the positive plate to *lead dioxide.*

The principle of the lead accumulator was first mentioned, so far as it is known, in 1803, by Ritter. The first practical application of it was made in 1860 by Gaston Planté, who made the first storage cells and for whom they were called Planté cells. Faraday is also accredited with contributing to the development of the storage cell. The early Planté cells were made in the manner described above. Later on it was found that this process was unnecessarily slow, and the "pasted" cells were devised, in France by Faure, and simultaneously in America by Brush. The "pasted" cell employs a stiff grid of lead and antimony alloy which functions as a supporting framework for a paste composed of lead oxides which is forced into the interstices of both sets of plates. The plates are then "formed" by a long, slow-charging process, which drives the oxygen out of the set of plates on the negative side of the charging line, and increases the proportion of oxygen in the other plate. The cell is then ready for use. There are a number of positive plates connected to one positive post, and a number of negative plates connected to a common negative post. As the current capacity of a storage cell is in proportion to the active surface of the plates, there is always one more negative plate than positive. This gives greatest capacity with minimum bulk. Each surface of each positive plate is faced by an active negative plate. The plates are separated by corrugated strips of wood or rubber. The rubber is more efficient, but much more expensive; and wood, sometimes with additional perforated thin sheets of rubber, is generally used in commercial types of cells. The wood is given special treatment to make it suitable for this purpose. The electrolyte is a solution of chemically pure water and sulphuric acid having a specific gravity of from 1,250 to 1,300. This is usually a proportion of about one part of acid to four parts of water, the exact ratio depending upon the specific gravity of the acid.

228. As the fundamental principle of all lead cells, and

the potential produced by the chemical action of them, is the same, it is unnecessary to undertake to describe the various makes. One of the best known firms manufacturing lead cells is the Electric Storage Battery Company, who manufacture several types of lead cells. The most popular of these, for general purposes, is known as the *Exide* cell; and this is the cell which is most frequently employed on seagoing vessels for the auxiliary source of power. In the Exide cell, the plates are made up of grids consisting of a series of staggered light weight bars placed vertically, and heavy bars placed horizontally. Between these are the pasted compounds, which are hardened like cement, so that the paste is locked in place by the horizontal bars. By an electrical and chemical process, the hardened paste is then converted into active material. The voltage of the Exide cell varies

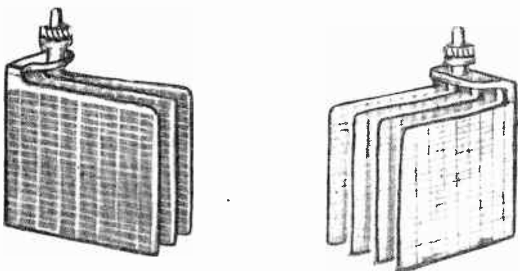


Fig. 150. Positive and Negative Plates of Exide Cell.

from 2.1 volts at maximum to about 1.8 at the minimum to which it can safely be allowed to fall without damage to the plates. Storage cells comply with the same laws for cells

Fig. 151. A Twelve-Volt Bank of Exide Cells.

in series and parallel which govern primary cells. They usually are sold in banks of 6 or 12 volts. For charging, the cells are arranged in series or parallel with the charging current, according to their number. If there is such a number of cells that their fully charged voltage would exceed the voltage of the charging current, they are connected in two or more series groups in parallel across the charging circuit. Otherwise, they are connected in series in the charging circuit. Figure 152 shows a simple lamp-bank charging panel, used as a variable resistance to regulate the current passing through the battery. While the lamp bank as a whole is seen to be in series with the battery and the line, the lamps individually are connected in parallel, and com-

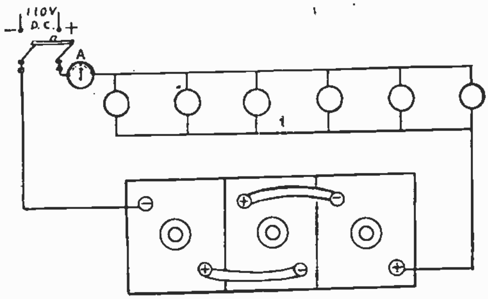


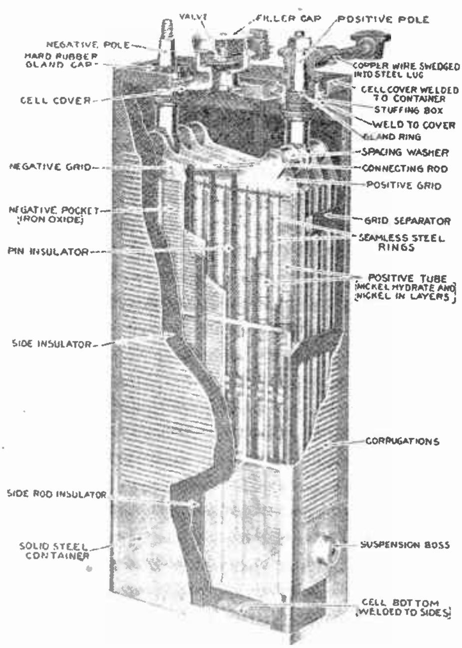
Fig. 152. Simple Lamp-Bank Charging Outfit.

ply with the law for *resistances* in parallel. The greater the number of lamps used, the greater will be the current flowing to the cells, because connecting resistances in parallel provides additional paths for the current, and thereby *reduces the total resistance.* A small ammeter should be connected in the circuit to indicate the current passing, and it should read in two ways, that is, have the zero in the center of the dial, and read amperes either to the right or left. This will show the direction of the current quickly, and prevent charging the cells in the wrong direction.

229. The *Edison* cell, which is the well known nickel-iron cell, is based on a different principle. It is much more complicated in construction than the lead cell. On the other hand, once completed and charged, about the only attention it needs is to keep it properly charged and clean, and to add water when necessary to replace evaporation. Steinmetz said: "The characteristic feature of the Edison battery,

which appears to me as the main advantage, is the complete *reversibility* of the chemical reactions which occur in it, with the materials—iron, nickel, and their oxides, in caustic potash as electrolyte—no chemical processes can occur which are not electrolytically reversible.

"In this respect the Edison appears to me essentially different from the lead battery, in which we know that there is an *irreversible* chemical process—the formation of lead sulphate, which means that if you discharge a lead battery you can never charge it again to the same capacity, but every successive charge and discharge reduces the capacity, be it ever so little. Therefrom it follows that the life of the lead battery must be limited—that its capacity must gradually decrease until at least one set of plates *has to be replaced.*



THE EDISON ALKALINE STORAGE CELL
A Masterpiece of Mechanical Construction

Fig. 153. Edison Nickel-Iron Cell.

It cannot be seen how an irreversible process could occur in the Edison battery. You can over-charge it or over-discharge it, can charge it with reversed polarity. Its life is limited theoretically only by mechanical destruction."

The Edison cell consists of a *positive* element of perforated nickel-steel tubes filled with *flaked nickel* and *nickel hydrate,* and a *negative* element composed of perforated nickel-steel pockets held in place by a grid and filled with hydraulically pressed *iron oxide* and *metallic mercury.* The electrolyte is an alkaline solution, consisting of 20 per cent *caustic potash,* 1 per cent *lithium hydrate,* and 79 per cent chemically pure water. Its voltage at maximum is 1.2 volts, being the nearest to the ideal of a 1-volt cell. Its minimum voltage on discharge is about .9 volts. It will be noticed that it is necessary to employ a larger number of Edison cells than of lead cells, to obtain a certain desired voltage; and this means a greater bulk for the power obtained. The following on the chemistry of the Edison cell is from literature of the Edison Storage Battery Company:

The fundamental principle of the Edison Storage Battery is the oxidation and reduction of metals in an electrolyte which neither combines with nor dissolves either the metals or their oxides. Also, an electrolyte which, notwithstanding its decomposition by the action of the battery, is immediately re-formed in equal quantity, and is, therefore, a practically constant element without change of density or conductivity over long periods of time. Therefore, only a small quantity of such electrolyte is necessary, permitting a very close proximity of the plates. Furthermore, it is unnecessary to take hydrometer readings until about three hundred cycles of charge and discharge have been made; this is simply to determine when it is necessary to empty out the old solution and put in new. The active materials of the electrodes being insoluble in the electrolyte, no chemical deterioration takes place therefrom.

The chemical reactions in charging the Edison Storage Battery are, (1) the oxidation from a lower to a higher oxide of nickel in the positive plate, and (2) the reduction from ferrous oxide to metallic iron in the negative plate. The oxidation and reduction are performed by the oxygen and hydrogen set free at the respective poles by the electrolytic decomposition of water during the charge. The charging of the positive plate is, therefore, simply a process of increasing the proportion of oxygen to nickel. The proportions of nickel to oxygen in definite oxides of nickel are as follows:

Atomic Proportions by Weight

	Ni	O	Ni	O
NiO	1	1	1	.273
Ni_3O_4	1	1.33	1	.364
Ni_2O_3	1	1.5	1	.409
NiO_2	1	2	1	.545

The relative amounts of oxygen necessary to oxidize nickelous oxide, or NiO—which is the oxide corresponding to the green nickel hydrate used in making the battery—to the various oxides, are given in the three reactions:

$$(1)\quad 6\,NiO + 2O = 2\,Ni_3O_4$$
$$(2)\quad 6\,NiO + 3O = 3\,Ni_2O_3$$
$$(3)\quad 6\,NiO + 6O = 6\,NiO_2$$

The NiO_2 is capable of reacting with NiO according to the reaction $NiO_2 + NiO = Ni_2O_3$. Ni_3O_4 is considered as a combination of $NiO + Ni_2O_3 = Ni_3O_4$.

From a chemical standpoint a charged condition of the cell would, therefore, be represented in the positive plate by an atomic ratio of nickel to oxygen of at least 1:1.5 (or Ni_2O_3), depending on the charge. A discharged condition would be represented by a ratio of 1:1.33 (Ni_3O_4), or lower, depending on the discharge.

The discharge of the cell is simply the reversal of the above reactions, the hydrogen reducing the higher oxides of nickel to lower oxides and the oxygen oxidizing the iron to ferrous oxide.

230. The *voltage* of any particular make or type of storage cell is always the same for that type, as is the case with the primary cells, regardless of *size*, and it rises and falls according to the state of charge and discharge and the condition of the electrolyte. The *capacity, in amperes,* of different makes of cells, depends upon the number of plates and their size. Most manufacturers turn out large and small cells, having correspondingly large and small capacity, for different uses. The ampere-hour capacity is usually stated on the name plate.

In the care of the lead-plate cells the specific gravity of the electrolyte is an important consideration, as it indicates the state of discharge of the cell. *Specific gravity of the electrolyte is understood to mean its weight compared* *to the weight of water.* It is determined by the use of a *hydrometer,* which is a device consisting of a syringe containing a float made of glass, with some small shot for weight at the lower end, and with a paper scale enclosed. As this rises out of the electrolyte drawn up into the syringe, the reading of the specific gravity can be seen on the scale. (For further information regarding storage batteries see chapter 39.)

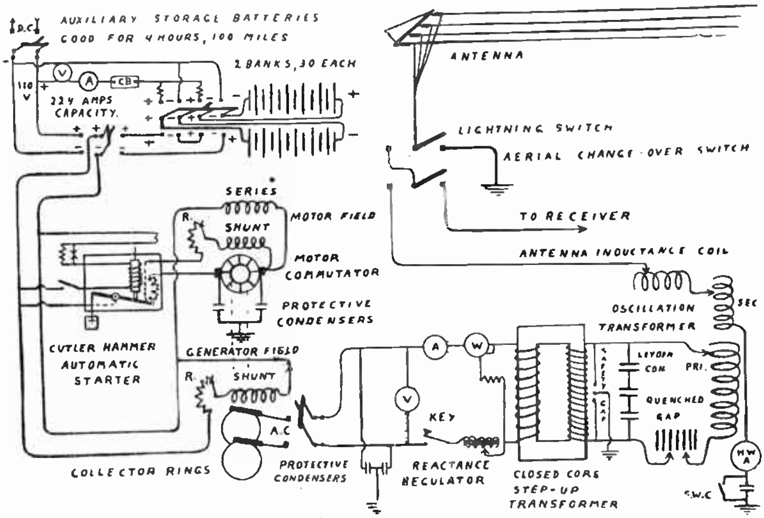


Fig. 154. Marconi Transmitter with Storage Battery Auxiliary.

The circuits of the spark transmitter are designated as follows:

1st circuit, d. c. motor-generator windings.

2d circuit, alternator armature and transformer primary.

3d circuit, secondary and high-potential condensers.

4th circuit, high-potential condenser, spark gap, and oscillation transformer primary.

5th circuit, antenna oscillation transformer, and ground.

The Marconi 2-K. W. 240-cycle spark transmitter was an assembled outfit, consisting of separate motor-generator, starting box, transformers, etc., mounted in a rack and on a table. It has been replaced by the panel types of apparatus shown in chapter 37. The fundamental circuits of all spark transmitters are the same, however, and this one is used as an illustration of the fundamental idea, and to bring together in one simple complete diagram the various pieces of appartus which have been taken up in part one of this book.

231. A simple storage battery control panel is shown in figure 154, connected for use as an auxiliary source of power with a 2-K. W. 240-cycle spark transmitter. When the four-pole switch is thrown in charging position the two banks of cells are connected in parallel across the supply line with suitable resistance on the positive side, and the voltmeter, ammeter and circuit-breaker included. It is possible to keep the storage cells on charge, at the same time that the transmitter is being operated from the source of power, by throwing the two-pole double-throw switch to the left. When the cells are to be used as power for operating the transmitter, this switch is thrown to the right, and the four-pole battery switch is thrown down, in the discharge position. This places the cells in series for discharge.

PART TWO

PRINCIPLES OF RECEIVING

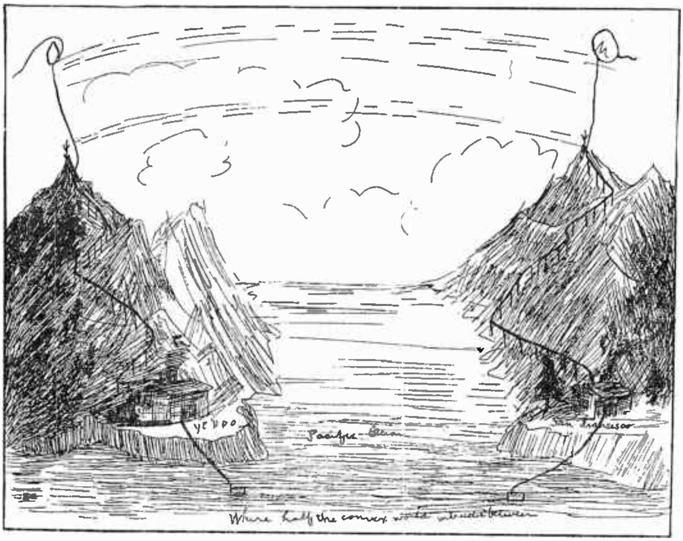


Fig. 155. Dr. Mahlon Loomis's Vision of Wireless Communication Between San Francisco and Japan. (Reproduced from drawing made by Dr. Mahlon Loomis in 1865, and now preserved in the archives of the Library of Congress, Washington, D. C.)

CHAPTER 26

Sound Waves

Pitch Frequency—Velocity of Sound Wave—Overtones Sonograph.

232. *Light, colors and the electromagnetic waves used for radio communication are believed to travel at the same velocity and through the same medium,* their only difference being that of *frequency.* If we change the *frequency* of the color, or light vibrations of any object, we cause a change that is registered by the human eye as another color. For instance, watch a horseshoe in a blacksmith's hands. When the metal is of different degrees of heat it appears to be of different colors. When the fire causes it to vibrate at a certain frequency it looks red; as the heat increases the color changes to yellow; and when it reaches the hottest point it appears to be white. As it cools, we can trace the color changes back to the point where the only light vibrations emitted by the horseshoe are the normal ones of the cold metal. The colors known to us are those of the spectrum. There are without doubt other light vibrations which pass unperceived on account of the limitations of the human eye.

233. *Sound waves* are known to be caused by the vibration of some *material object* which causes corresponding vibrations in the air, or through liquids, wood or metal. Sound waves do not travel through the medium which is common to light, color and electromagnetic waves. Light can pass through a vacuum, as can be verified on every hand by the familiar evacuated electric light bulbs and vacuum tubes used in radio work. *Sound waves do not pass through a vacuum.* A gas, liquid or material object is necessary in order that they may travel. An electric bell placed inside of an evacuated glass receptacle could be *seen* to ring, but it could not be *heard.* The vibratory motion causing sound can frequently be seen, as in the case of a violin or guitar string. It can also be felt. In the *Encyclopedia Brittanica* we find: "Sound is due to vibration. In every instance in which the sensation of sound is excited, the body whence the sound proceeds must have been thrown into a state of agitation or tremor, implying the existence of a vibratory motion, or motion to and fro, of the particles of which it consists.

If a glass tumbler be struck so as to yield an audible sound, the existence of a motion of this kind may be felt by the finger lightly applied to the edge of the glass; on increasing the pressure so as to destroy the motion, the sound forthwith ceases. Water or spirits of wine in a glass, vibrating with sound, will exhibit a ruffled surface. Sound waves, like light waves, exercise a small pressure against any surface upon which they impinge."

234. Sound waves emitted from a vibrating object will cause corresponding vibrations in other objects that are of such dimensions and density that they can vibrate at the same frequency. Sometimes a chandelier will vibrate when one particular note of a piano is struck. Sometimes the human voice will be reproduced in what is known as an echo when the vibrations appear to be repeated a second or third time in the hills, or the walls of certain buildings.

235. The velocity of sound waves is much less than that of the various electromagnetic waves, being about 332 meters, or a trifle over one-fifth of a mile per second. It takes practically five seconds for sound waves to travel a distance of one mile. The difference between the velocity of light waves and sound waves can be demonstrated through our physical senses by observing how much time passes after a flash of lightning is seen before the roar of the thunder can be heard, or how we can see the steam rise from a locomotive whistle before we can hear the sound of it. The velocity of sound varies somewhat with changes in temperature, there being an increase of about .6 meter in velocity for every degree Centigrade rise in temperature.

236. The *pitch* of a sound, as registered by the human ear, depends on the *frequency of the sound vibrations*. The faster the sound vibrations the higher the pitch, until they become too fast for us to hear; and going lower, we find a place where the pitch is so low that the ear can not respond to the vibrations. A violin string that vibrates with a low tone does not radiate as many vibrations per second as when it is vibrating with a higher pitch. Some people can hear certain very high and very low tones that others cannot hear; and certain delicate instruments have been invented which can record sounds, the existence of which we would be otherwise unaware of.

237. The *volume,* or amplitude, of a sound depends upon the *energy* of the vibrations. Given a sound of a certain *pitch,* it may be loud or faint, according to the amount of *force behind it.* A cornet player can make a note of the same pitch loud or soft by the amount of pressure placed back of it by his breath.

238. Aside from pitch and loudness, sound has another characteristic—that of *quality.* A violin and a cornet may each emit a note of exactly the same pitch and loudness, yet there would be no mistaking the note of one for that of the other. This difference in quality is due to what are generally called *overtones;* and these are, when analyzed, found to be made up of many small waves, or vibrations, which travel along with the main waves, being of a higher frequency, and producing little sounds of a higher pitch than the main sound. Among singers this individual quality produced by the characteristic overtones is known as the "timbre" of a person's singing voice. This is the French equivalent of *sound,* or *ring.* When sound waves are compared to water waves, one may imagine them as consisting of large undulations of fluctuating length and amplitude, but traveling along at the same velocity, without breakers, over the surface of which are many small ripples blown by the breeze. Water waves frequently present exactly this appearance. In sounds, these small overtone waves so vary the form of the main wave that it is possible to know the voices of our friends without seeing them; and to recognize, by their characteristic quality, the sounds of the different musical instruments.

239. The range covered by audible sound waves is about eleven octaves, the lowest being "low C" of 16 vibrations per second, and the highest that of a whistle far above musical tones, having a frequency of 32,768 vibrations. The average ear, however, cannot hear sounds of a frequency of over 20,000 vibrations, while many people with good hearing can hear no more than 16,000 vibrations. The ordinary telephone receivers are not responsive to frequencies of over 10,000. In radio work, frequencies below 10,000 are referred to as *audio-frequencies.* Lacking the velocity and momentum of light waves, sound waves are limited to a range of *distance* that corresponds with their lower velocity. While vibrations of radio frequency have been transmitted around the earth, it it not likely that *sound* vibrations have ever traveled through

the air for a distance of more than a few miles. It will be seen that, *in order to transmit the human voice through space, or to make a series of "dots and dashes" intelligible at a receiving station, electric waves must be propelled, at radio frequency, and these vibrations must be made to cause sound vibrations on some material object, in order that they may be heard.*

240. Sound waves can be photographed, and the application of this idea in recording the wave form of music and speech along the edge of a moving-picture film has been successfully accomplished. Entire operas have been reproduced in this manner, the actors appearing to be simultaneously moving on the screen and singing, exactly as they had done in the original performance. When the picture is projected, the pictured record of the sound waves is reflected on a piece of selenium, which is extremely sensitive to light and automatically varies its electrical resistance according to the intensity of the light falling upon it. Or, in a somewhat later apparatus, the light is thrown on an electric bulb containing a gas which, it is claimed, reproduces the original sounds with greater fidelity. This is arranged in an electric circuit equipped with a loud speaker, and the variations of resistance are repeated in current fluctuations, causing the loud speaker to send out a reproduction of the original sound waves.

241. In its simplest form, the photographing of sound waves consists of subjecting a ray of light, which is reflected on a revolving mirror, to the effects of the compression and rarefaction of the air due to the sound waves, and photographing the reflected ray of light on the moving photographic film. One way of accomplishing this is to place a thin sheet of rubber or gold-beaters' skin between a mouthpiece and the stopcock in a small gas jet. Then, when the voice is projected into the speaking tube, the flexible diaphragm of rubber or skin moves, and causes a variation in the gas pressure, which causes a variation in the flame; and this variation caused by the sound waves will show on the revolving mirror and be recorded on the film. This has been known for several years, but has only recently been applied to *reproducing* sounds. A somewhat later method con-

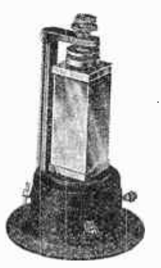


Fig. 156. Motor-Driven "Sonograph" Mirror

sists of using a small circular mirror attached to a diaphragm by means of a thin wire and a pulley. For every fluctuation of the diaphragm there is a like fluctuation of the mirror; and this can be photographed, if a ray of light

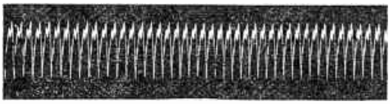


Fig. 157. Sound-Wave Photograph of Vowel E.

from the sun, or a powerful electric lamp, be focused on it through a lens. This will show distinctly the variations caused by the overtones, as well as the fundamental waves.

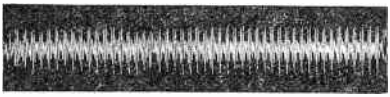


Fig. 158. Photograph of Wave Form of "Middle A" International-Pitch Tuning Fork, 435 Vibrations Per Second.

242. An understanding of sound waves is essential to the operator in the handling of modern radio devices. It is the basis of the modulation systems used in radiotelephony; and is studied in connection with various types of amplifiers. Sound waves, since the development of radio, have found many new applications. For instance, the U. S. Navy has developed a system of taking soundings which is more efficient than the older method. Sound waves are produced and propagated through the water, and, by means of telephone receivers, it is possible to calculate accurately the distance from which the sounds are *reflected* by the bottom of the sea. While this is not strictly radio work, Admiral Hooper states that, "The services of radio operators who are competent in receiving incoming radio signals are desirable if not necessary for best results in sound work." (See paragraph 521.)

CHAPTER 27

The Telephone Receiver

History—Construction—Various Types of Receiving Telephones—Telephone Efficiency—Molecular Theory of Sound Waves

243. The telephone receiver is an important part of modern radio receiving apparatus. It is an instrument based on the laws of magnetism, its sensitiveness to variations in volume and quality of tone being quite remarkable. The invention of the telephone, in the United States, is generally accredited to Alexander Graham Bell. It appears, however, to have been invented and given its present name by one Philip Reis, in Frankford, Germany, exhibited before scientific societies in England and Germany in 1865, and known prior to that time. The telephone is referred to several times in the memoranda left by Dr. Mahlon Loomis, dating from 1865. Bell's instrument was patented in 1876. This patent was the cause of much litigation, resulting in a decision of the U. S. Supreme Court that Bell was entitled to the patent to the telephone, on account of his having made it commercially successful.

(See *Philip Reis, Inventor of the Telephone,* by Sylvanus Thompson, D.Sc., Professor of Physics, Bristol.)

244. The usual type of telephone receiver consists of a thin metallic disc placed loosely over a magnet, which holds it lightly in place, and operated by the variation in current passed through a solenoid which is wound around the magnet. When the current in the solenoid is increased or decreased, the increase or decrease in magnetism attracts or releases the disc, and this movement of the disc, or *diaphragm,* produces *sound waves* which can be heard. The solenoid is supplied with current from batteries when used for land-line telephony. In radio, the energy of the electromagnetic waves intercepted by the receiving antenna is sufficient to operate the diaphragm. The telephone transmitter, in the early forms, was exactly like the receiver, but the most familiar modern types contain a small chamber filled with carbon granules, which act as a variable resistance. (See paragraph 342.) When the sound waves of the voice, music, etc., are projected against the telephone transmitter, the compression and releasing of the transmitting diaphragm

causes fluctuations in the current with which the telephone transmitter is energized, and these fluctuations, when conveyed to the solenoid of the receiving telephone, either by land or radio telephony, cause identical movements of the diaphragm of the receiving telephone, and *reproduce the sound waves of the transmitter.*

Mr. Thomas A. Watson, Bell's assistant at the time that he was working out his idea of the telephone, describes this early development in a brochure entitled *The Birth and Babyhood of the Telephone.* Bell had been working with a "vibrating reed," which was a form of buzzer. It had a flattened-out piece of steel clock spring arranged as in figure 159. When current was passed through the coil the reed would

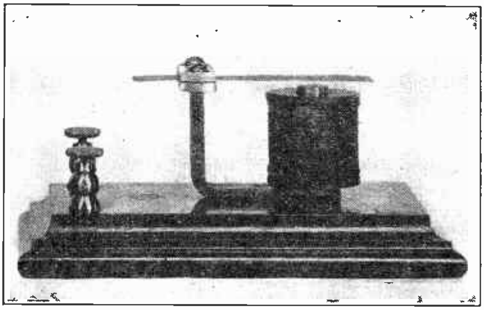


Fig. 159. Bell's Vibrating Reed.

vibrate. By tuning the reed to vibrate at a certain frequency, and placing another vibrator tuned to the same frequency at a distance from the first one, but electrically in series with the same solenoid, Bell expected to perfect a "harmonic telegraph" for multiplex communication. By using reeds of various pitches at both ends of the circuit, it was hoped that messages could be sent in these different pitches and selected by their pitches at the receiving end. This was not perfected by Bell, but led to his first telephone. One day Mr. Watson plucked one of the reeds which had stuck to the magnet, and this made a sound at the other end, which was different from that of the buzzer. In other words, the *sound wave* had passed along the wire to the ears of Mr. Bell. Immediately Bell gave directions for the construction of his first type of telephone. Mr. Watson says: "I was to mount a small drumhead of gold-beaters' skin over one of the receivers, join the center of the drumhead to the free end of the receiver spring and arrange a mouthpiece over the drumhead to talk into. His idea was to force the steel spring to follow the vocal vibrations and generate a current of electricity that would vary in intensity as the air varies in density during the utterance of speech sounds." The varying of the magnetic field, as the reed changed its position, caused the sound waves to produce corresponding changes in the current passing through the coil, and reproduced these fluctuations at the receiving end.

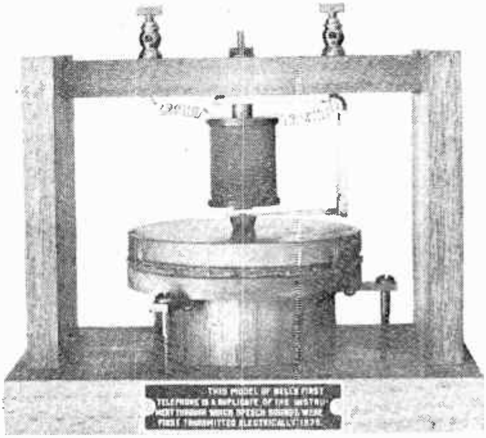


Fig. 160. Bell's First Telephone. (1876.)

The cylinder, in the instrument shown in figure 160, was hollow, the opening coming through the base board at the bottom, and not showing in the photograph. The device was held in the hand with the opening against the ear or mouth.

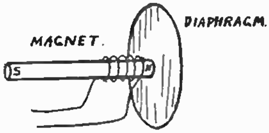


Fig. 161a. Principle of Bell's First Telephone Instrument (1876).

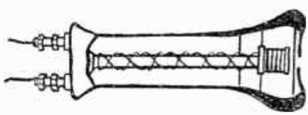


Fig. 161b. Later Type of Single-Pole Telephone Instrument, where the Magnet and Diaphragm are enclosed in a Hard Rubber Case.

245. The single-pole receiver was used for many years on the Bell telephone lines. However, certain difficulties were encountered in its use. One of which was that in cold

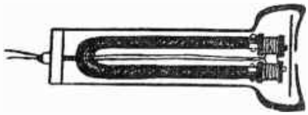


Fig. 162a. Double-Pole Receiver.

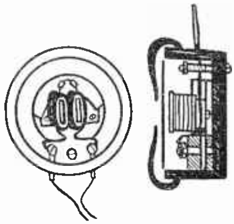


Fig. 162b. Watch-Case Receiver.

Fig. 163a. Modern Telephone "Head Set" used in Radio.

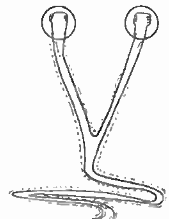


Fig. 163b. Manner of Connecting Two Telephone Receivers in Series to form a "Head Set."

weather the diaphragm had a tendency to be drawn against the pole and to remain there without vibrating. It has been found that a double pole, or horseshoe magnet, overcomes this trouble; and bipolar receivers have replaced the single-pole variety. The first double-pole receivers were of the long type commonly used in "house telephones." Receivers developed for radio work generally consist of two short "spools" wound with a great many turns of fine wire and connected so as to maintain poles of opposite polarity. The spools are wound over soft iron cores, having a high magnetic permeability, and these cores are attached to opposite ends of a laminated semi-circular permanent magnet, which keeps the soft cores magnetized. These are known as "watch case" receivers. The windings of the telephone solenoids are connected to the circuit in which the instrument is used by means of a "telephone cord," consisting of two insulated woven tinsel conductors, enclosed in a cotton casing.

246. *The efficiency of a telephone receiver depends upon the thickness and permeability of the diaphragm, the number of lines of force of the permanent magnet, the metallic resistance of the windings, and the inductive and capacity reactance of the windings.* The resistance depends upon the size of the wire used for the spool windings, and the number of turns made in each solenoid. The latter are often referred to as *"ampere turns."* The strength of the magnetic field obtained is the product of the current and the turns per centimeter. With a weak current and a great many turns of wire the same amount of *magnetism* may be secured as with a smaller number of turns of wire and a stronger current. Telephone receivers are operated on pulsating current. Alternating current will either cause the diaphragm to adhere to the magnets or produce a continuous roar. With pulsating current we have a certain amount of reactance in the coils. Some companies mark their telephone receivers as rated in so many ohms a.c. resistance. This is rated at different frequencies with different manufacturers. Telephones designed for land-line have usually a resistance of from 50 to 100 ohms. Radio telephone receivers range from 1000 to 3000 ohms each and, as two of them are placed in series, the total resistance is twice this amount. Radio telephones are made with many more turns of wire on the spools than the line-wire instruments, as this gives greater sensitiveness to the weaker signals for which they are used. When used in a vacuum tube receiving set, the total impedence of the telephones should be approximately that of the plate circuit of the tube.

247. Many variations of the original arrangement of magnets and diaphragm have been invented, with the idea of improving the receiver. One of the first of these was the Baldwin phone. This receiver consists of a single long magnet bent into a ring and a single winding. A solid U-shaped iron extension is fastened to each end of the ring-shaped "horseshoe" magnet. The solenoid is wound on an oval-shaped spool and placed between the ends of the extensions of the magnet. Placed inside of a narrow slit through the center of the spool is a thin strip of sheet iron, balanced on a pivot. This strip is called an "armature" by Mr. Baldwin. The armature vibrates under the influence of the alternate polarity of the two U-shaped extensions of the magnet when

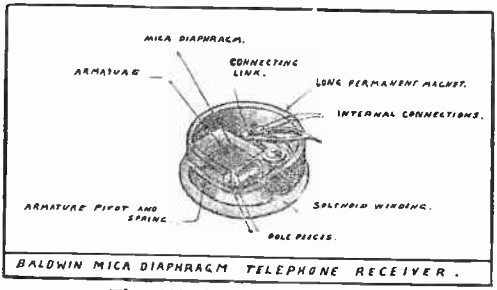


Fig. 164. Baldwin Telephone.

current is passed through the solenoid; but, on account of its being pivoted at the center, its vibration is accentuated into a rocking motion, the actual distance of the movement of each free end being about one-sixteenth of an inch—a much greater distance than is covered in the vibration of the regular metal diaphragm. As this armature is necessarily small, and imbedded in the center of the mechanism, it will not, by itself, produce sound waves of sufficient volume for the reception of signals. To procure this result, a circular diaphragm of the regulation size, but composed of sheet mica, is attached to one end of the vibrating armature by a small metal pin; and the non-magnetizable mica diaphragm is mechanically forced to vibrate at the same rate as the armature. This produces a telephone receiver which is sensitive to weak signals, and which is free from metallic rattle.

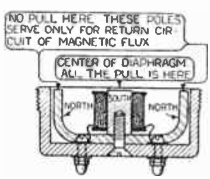


Fig. 165a. "Rico" Three-Pole Telephone Receiver.

Fig. 165b. Four-Pole Telephone.

248. Another variation of the regular telephone idea is shown in the three-pole receiver. The idea in this is to place all of the magnetic pull on the diaphragm exactly in the center, instead of having it distributed over a wider area as in the ordinary two-pole receiver. There is only

one spool, in the center, wound so as to present a south polarity to the diaphragm, and two other poles are provided by permanent magnets only. Still another type appears with four poles, wound with four solenoids, for which a very "mellow tone" is claimed. An English telephone receiver, manufactured by S. G. Brown, is provided with a vibrating reed attached to a non-magnetic diaphragm, and this reed can be regulated by a set screw. This is known as a "tuned telephone." The purpose of tuning it is to adjust the instrument so that the diaphragm may vibrate at its natural or "resonant frequency."

249. When electric waves of radio frequency are emitted from a transmitting antenna, corresponding oscillations are excited in the antenna circuit of any receiving station within range that can be adjusted to resonance with the frequency, or wave length, of the transmitter. And with suitable tuning devices, and a rectifier, known as a "detector," these electric waves, if they have any *group-frequency* within audibility, cause the telephone diaphragm to vibrate in accordance with the audible group-frequency, and signals are heard.

The *loudness* of the sound heard at the receiving station is in proportion to the force or pressure with which the waves were emitted from the transmitter—or upon the voltage of that mechanism—also upon the degree of sensitiveness and tuning to these waves at the receiving station and upon the distance of the transmitter. If the receiving apparatus is tuned to the fullest possible degree of resonance with the transmitter, the greatest amount of current possible under existing conditions will be induced into the receiver; but given an emitted wave of great pressure, if the receiver is not tuned in resonance with it, the tone heard in the telephone will be weak, or it may not be heard at all. The *pitch* of the sound heard depends upon the frequency at which the telephone diaphragm is made to vibrate. The *quality* of the tone depends upon the quality and smoothness of operation of the sound-frequency devices at the transmitting station—or on the character of the overtones produced by the transmitting station.

250. The theory of the vibration of the telephone diaphragm under the influence of sound waves is shown in illustrations 166 and 167. The sound wave of the spoken word

is actually a motion to and fro of the tiny molecules composing the air about us. Each rising and falling inflection of pitch, each change in quality, and each position of the lip and tongue, cause these molecules to move in a different way, and simultaneously actuate the telephone diaphragms of transmitter and receiver with a different motion. In radiotelephony the sound waves of the voice or music are transmitted through space and actuate the receiving telephones exactly as if they had come along a wire. In radiotelegraphy the radio-frequency waves are transmitted in dot and dash groups, reaching the receiving telephone in the

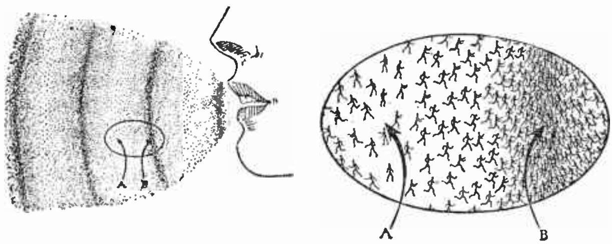


Fig. 166. Sound Waves Issuing from the Mouth of a Speaker, and the Manner in Which the Molecules Dance Back and Forth.
(Courtesy John Mills, in *The Magic of Communication.*)

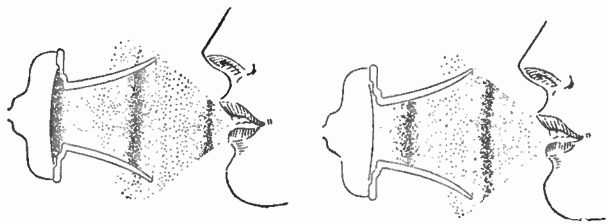


Fig. 167. Illustration of the Manner in Which the Molecules of Air Press the Telephone Diaphragm in, when they rush against it, and permit it to spring out when they recede from it. (John Mills.)

form of some type of electric current fluctuation, which causes the diaphragm to vibrate and reproduce the sound and pitch of spark transmitter, chopper interrupter, etc.

CHAPTER 28

Early Detectors

Function of Receiving Apparatus—Early Forms of Detectors—History of Message Sent by Dr. Mahlon Loomis in 1865—Historical Development of Receiving Circuit.

251. *The function of a radio receiving apparatus is to absorb a portion of the electromagnetic waves emitted by a distant transmitter, and by use of the energy thus absorbed to operate some manner of signal making device.* Some kind of antenna is necessary. A single grounded vertical wire is theoretically a good antenna, but in practice it is found to be mechanically inconvenient. Dr. James Harris Rogers, inventor of the underground antenna, is authority for the statement that Dr. Mahlon Loomis in his experiments in the hills of Virginia, employed a vertical wire antenna by hanging the wire from a kite. A single horizontal wire is often used for modern broadcast receiving sets. On board ship, and in the larger land stations, the inverted L or the T are most frequently employed. *In order to respond to the passing vibrations, the receiving apparatus must be of such inductance and capacity as to be capable of vibrating at the same frequency as that of the waves which it is desired to receive.*

252. Many methods of detecting the intercepted electromagnetic waves have been used at different times, and these have been known by different names, but their function has always been to transform the intercepted waves into recognizable signals. The first experiments at receiving communications "without connecting wires" appear to have been confined to simply proving the existence of an electric current induced into the receiving apparatus at the instant in which the transmitter was placed in operation. Dr. Loomis, in some of his tests, employed a galvanometer to indicate the presence of this current. With hanging vertical antennæ and a covering of "fine gauze of copper wire" attached to his kites, elevated to a great altitude, and "a good ground," in 1865 he caused the instrument at the receiving station to be deflected at the instant the instrument at the transmitting station eighteen miles distant was electrically closed. The following account of this historical event is from the diary of Dr. Mahlon Loomis:* "From the two moun-

*See Manuscript Division of Library of Congress, Washington, D. C.

tain peaks of the Blue Ridge in Virginia, which are only about two thousand feet above the tide-water, two kites were let up, one from each summit, eighteen or twenty miles apart. These kites had each a small piece of fine copper wire gauze about fifteen inches square attached to their under side and connected also with the wire six hundred feet in length which held the kites when they were up. The day was clear and cool in the month of October, with breeze enough to hold the kites firmly at anchor when they were flown. Good connection was made with the ground by laying in a wet place a coil of wire, one end of which was secured to the binding post of a galvanometer. The equipments and apparatus at both stations were exactly alike. The time pieces of both parties having been set alike, it was arranged that at precisely such an hour and minute the galvanometer at one station should be attached, to be in circuit with the ground and kite wires. At the opposite station separate and deliberate half-minute connections were made with the kite wire and the instrument. This deflected or moved the needle at the other station with the same vigor and precision as if it had been attached to an ordinary battery. After a lapse of five minutes, as previously arranged, the same performance was repeated with the same results. Then fifteen minutes precisely was allowed to elapse, during which time the instrument at the first station was put in circuit with both wires, while the opposite one was detached from its upper wire, thus reversing the arrangements at each station. At the expiration of the fifteen minutes the message, or signals, came in at the initial station, a perfect duplicate of those sent from it, as by previous arrangement. And although no transmitting key was made use of nor any sounder to voice the messages, yet they were just as exact and distinct as any that ever traveled over a metallic conductor. *A solemn feeling seemed to be impressed upon those who witnessed the little performance as if some grave mystery hovered there around that simple scene.* It continued to transmit signals only about three hours when the circuit suddenly *became inoperative by the moving away of the upper electric body.* Hence it is that *high regions* must be sought where disturbing influences cannot invade." Among the witnesses mentioned in Dr. Loomis's diary were Senator Pomeroy and Representative Bingham of Ohio. It is evident that Dr. Loomis also used the telephone, although research has not yet disclosed exactly how he did this, or what manner of detector he may have used. A yellowed newspaper clipping dated 1878, and bearing the name of Philadelphia, but from which the name of the particular paper is missing, states the following: "A Washington letter to the *Hartford Times** says "Mention was made some time ago of the experiments of Dr. Loomis in the mountains of West Virginia. His experiments are conducted from high hills or mountains, though he has telegraphed as far as eleven miles by having kites raised at each end of that distance, flying them with a fine copper wire instead of a string. The instant they reached the same exact altitude or got into the

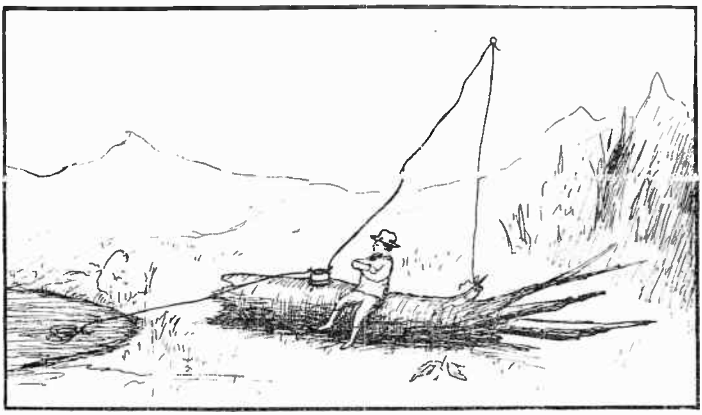


Fig. 168. Reproduction of Drawing found among effects of Dr. Mahlon Loomis, illustrating his experiment with a Galvanometer to detect signals (1865). (Original now in archives of Library of Congress, Washington, D. C.)

same current, telegraphic communication by aid of an instrument similar to the Morse instrument could be carried on as perfectly as if the two kites were connected with wires. The *lowering* of one kite would, however, break off communications immediately. This demonstrated to the professor that his wires should be stationary to keep up a constant communication. Accordingly, he built a kind of telescopic *tower* at the top of two high hilltops about twenty miles distant, and from them put up a steel rod by which a certain

*The author has located the Washington correspondent of the *Hartford Times* of that date, and found him to be Mr. MacCarty, known to the readers of that time as "Mac"; and Mr. MacCarty corroborates the above statements as having been written by him to the *Hartford Times* in the year 1878.

aerial current of electricity was reached. For months at a time he has been able to telegraph from one tower to another. A heavy storm disarranges the connection, but it can be readily restored after the storm has passed. In this respect it is not more unreliable than the ordinary telegraph connections by wire, which are broken up by many storms. A letter was received from Professor Loomis some days since, by Colonel D. C. Forney, of the Sunday *Chronicle*, in which he said that recently he had met with the most remarkable success in his experiments, and had demonstrated by repeated tests that *the telephone could be used as easily as the Morse instrument, and that of late he had done all of his talking to his assistant, twenty miles away from him, by the telephone, the connections being aerial only.*' "

253. In a way, Hertz's loop might be considered as an early form of detector, in that it served to indicate the existence of the received energy, which would jump across the gap in it, when the loop was turned in the right direction (see paragraph 188). The idea of a spark gap as an indicator of intercepted electromagnetic waves was later used

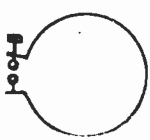


Fig. 169. Hertz's Receiving Loop (1881.)

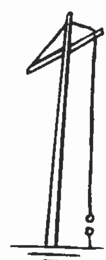


Fig. 170. Spark Gap as Detector in Receiving Antenna.

in a simple verticle antenna. It is interesting only historically, as it has, of course, been obsolete for practical reception of signals for many years. The next type of receiving indicator was the sounder of the line telegraphy. As the sounder requires a rather strong current to be worked successfully, it was necessary to operate it by means of a magnetic relay. This was the first type of receiver patented by Marconi, and probably the first to include a rectifier as a part of its equipment. In this, the rectifier was the now obsolete coherer. The relay is constructed somewhat like a sounder, except that the lever is of much lighter weight. It was connected in the circuit used for receiving the current from the antenna, and the vibrating strip, sometimes called an armature, was used to break and make contact of a second circuit consisting of the sounder and a bank of batteries. In this receiver, the high-frequency current set up in the antenna by the received electromagnetic waves was rectified to a one-way pulsating current by the coherer. The relay then, having too great inertia to vibrate at the speed of the one-way pulsations, responded to the groups of rectified current.

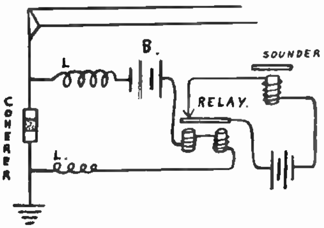


Fig. 171. Marconi Receiver (1897).

254. The *coherer* is worth studying, on account of its important influence on the development of wireless telegraphy. It was the first true rectifying detector, and although it was in practical use for several years, an exact explanation of the causes underlying its action was never reached, and its performance remains somewhat of a mystery. It seems possible that there may be some connection between the action of the coherer and the laws of magnetism but, so far as we have been able to ascertain, this has never been proven. The story of the coherer, according to *Fleming's Manual,* is as follows: "As far back as 1835 Munk observed that a mixture of tin filings, carbon, and other materials in a loose condition was non-conductive to electricity,* but became conductive on passing a discharge from a leyden jar through it. S. A. Varley, in 1852, noticed a remarkable fall of resistance of masses of metallic filings under action of

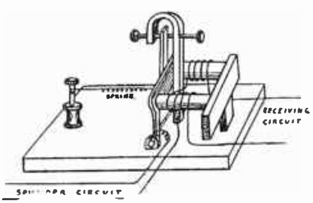


Fig. 172. Magnetic Relay.


Fig. 173. Coherer. (Actual Size.)

*Direct Current.

atmospheric electric discharges. In 1866 A. and S. A. Varley applied this discovery in the construction of a *lightning protector* for telegraphic purposes. In 1878 D. E. Hughes appears to have discovered that a tube full of zinc and silver filings placed in series with a voltaic cell and a telephone became conductive under the action of an electric spark at a distance. In 1890 E. Branly, of Paris, rediscovered this important fact and, confirming the observations of previous researches, added much new knowledge. He noticed that an electric spark had the power of suddenly changing the electric conductivity of a loose mass of metallic filings placed a long way from the spark. Branly constructed his metallic-filings spark *detector* by placing in a tube of non-conducting material some filings loosely packed between two metal plugs. In the same year G. Marconi described in a British patent specification a greatly improved form of metallic-filings oscillation detector constructed in the following manner: In a small glass tube he placed two silver plugs fitting the tube tightly. The inner ends of the plugs were polished and slightly amalgamated with mercury and brought within a couple of millimeters of each other. The interspace was filled with a small quantity of nickel and silver filings. The glass tube was then exhausted and sealed. Marconi thus constructed an extremely sensitive form of imperfect contact oscillation detector, which under the influence of feeble oscillations set up by electric waves passed from a condition of high resistance to a condition of low resistance." With the coherer they experienced considerable annoyance due to the fact that it was necessary to jar it to return it to its original non-conductive condition, hence several arrangements were devised for automatically tapping it, including clockwork devices. The tapping arrangement was known as the *decoherer*. The coherer, by responding to lightning in exactly the same manner in which it responded to electric waves used as telegraphic signals, proved the similarity of lightning and the electric waves used in radio communication. With all forms of detectors great annoyance is experienced at times with what is called static, this signifying the interference of atmospheric electricity. A distant flash of lightning may cause a roar in the receiver which will completely drown out the telegraph signals.

255. With the detector located in the antenna circuit, as in figure 171, there was no possibility of tuning the receiving

apparatus, and in 1898 Sir Oliver Lodge perfected a receiver in which the detector was removed to a second circuit. Lodge's receiver was also equipped with *telephones* and a condenser shunted across the telephones. Aside from the coherer, this apparatus is practically the same as the fundamental circuit of the crystal-detector set used today. The inductively coupled transformer, consisting of a primary connected in

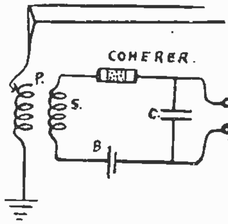


Fig. 174. Lodge Receiver with Inductively Coupled Transformer and Telephone Receivers ((1898).

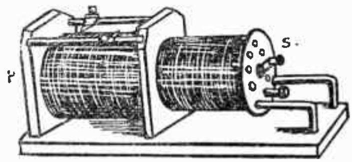


Fig. 175. Small Receiving Transformer with Variable Contact Studs.

the antenna circuit and the secondary connected in the detector circuit, made possible a degree of coupling between the receiver proper and the antenna, and provided a way for tuning out interference. This became known as a "loose coupler." By bringing out leads from sections of the windings, and arranging for variable contacts to these, it became possible to vary the inductance of the circuits, and hence to increase its range of adaptability to different wave lengths. By removing the detector to the secondary circuit, the resistance of the antenna circuit was reduced, thus reducing the local damping of the received electric waves.

256. In 1900 Marconi patented another receiver, still using the coherer but otherwise greatly improved. In this receiver he used telephones, a transformer, and variable condensers to vary the capacity of both circuits. After the coherer and decoherer, two other types of detectors were in use for some time, before giving way to those employed today. These were the magnetic and the electrolytic detector.

The *magnetic detector* was based on a discovery of Professor Rutherford, in 1895. He found that a small permanently magnetized needle, when suspended at the end of an electromagnet, would be deflected by the rise and fall of the current in the winding of the electromagnet. This idea was applied in slightly varying ways by different experimenters, a perfected form of it being patented by Marconi in 1902. The Marconi magnetic detector consisted of a pair of horseshoe permanent magnets which were slowly revolved over an electromagnet, the windings of which were connected with a telephone. Later he patented a better type which was equipped with two wooden discs grooved on the edges and driven slowly by clockwork. A band, or belt,

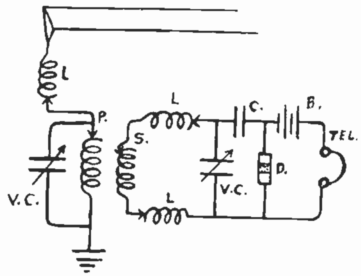


Fig. 176. Marconi Receiver (1900).

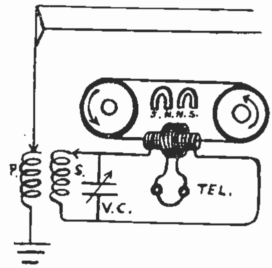


Fig. 177. Marconi Magnetic Detector.

made of silk-covered fine wires, moved over these pulleys, passing through a small glass tube which was wound with wire, and which was connected in circuit with the secondary of the receiving transformer. Around this, and insulated from it, was another coil of wire which was connected in circuit with the telephones, making a third circuit. Above the two coils were placed the pair of horseshoe magnets with their north poles next to each other. The demagnetizing and magnetizing of these magnets by the action of the received oscillating current caused changes that made a buzzing sound in the telephones. This detector was employed extensively by the English Marconi Company on seagoing vessels for several years.

257. The *electrolytic detector*, as its name implies, consisted of an electrolyte in a container. The solution was a 20 per cent. sulphuric or nitric acid. The electrodes consisted of silver-coated platinum wire, about the thickness of a hair, known as Wollastan wire, and it was necessary to melt off the silver at the point to obtain a good contact and a sensitive condition of the detector. Operators experienced great annoyance with this detector after static interference which would burn or roughen the end of the contact wire, making it necessary to again melt the end of the wire to restore the

detector to working condition. Also it was possible to spill the electrolyte. The electrolytic detector was patented in 1903 by Fessenden.

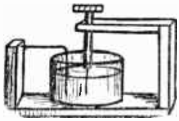


Fig. 178. Fessenden Electrolytic Detector.

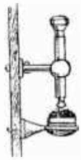


Fig. 179. Panel-Mounted Carborundum Detector

The various novel types of early detectors were replaced by rectifying crystals. For several years the standard receiving apparatus on both sea and land consisted of a "loose-coupler" tuning arrangement with a crystal detector. This might be called the intermediate period in the development of radio communication, the crystal detector apparatus filling the time, historically, between the more or less experimental earliest detectors and the modern vacuum-tube apparatus.

CHAPTER 29

Crystal-Detector Receiving Apparatus

Various Materials Used for Crystal Detectors—Crystal-Detector Receiving Circuits — Action of Crystal in Receiving Circuit — Receiving Condensers—Characteristics of Carborundum—End-Turn Switch—Buzzer Tester—Potentiometer—Variocoupler—Crystal-Detector Amplifier and Loud Speaker.

258. The only detectors used to any extent in practical receiving apparatus at the present time are vacuum tubes and crystals. Many different minerals are employed for crystal detectors, their value for this purpose being in proportion to their unilateral conductivity or rectifying property. Contact points of various types, generally consisting of some form of a spring, are arranged so that they can be pressed against the crystal and moved for the purpose of "exploring" it, in seeking its most sensitive spot. In some cases the crystal is imbedded in a small cup containing Wood's metal, which is a soft metal having a low melting point. Other detectors are fashioned with a cup and small screw which presses against the side of the crystal. The latter arrangement provides means for experimenting with the crystal in different positions, which in some cases is an advantage. The most popular of the minerals used for crystal detectors are *galena, carborundum, iron pyrites* and *fused silicon*. *Galena* is a natural, or synthetic, lead sulphide, which forms in cubic crystals and has a grayish luster similar to silver. It is used with a small spring contact of fine steel wire attached to a movable arm. *Carborundum* is an artificially manufactured crystal—carbide of silicon—which is the result of burning coke and sand in an electric furnace with carbon granules used as a conductor. In its commercial form it is used extensively in the manufacture of grinding wheels, into which it is moulded after being pulverized. It is used with either a spring-wire contact or a heavier blunt steel point pressed well down into a crevice of the crystal and a local battery. *Silicon* is also made in an electric furnace, being produced by subjecting a mixture of magnesium and sand to a high temperature, and afterwards treating this product with acids and molten zinc, until the pure crystalline silicon remains. This may be used with either a spring-wire contact or a small pointed piece of antimony. It does not require a battery, and when properly adjusted forms an excellent detector. *Iron pyrites* is the familiar "fool's gold,"

which on account of its yellow glitter has fooled prospectors from time to time. It is natural sulphide of iron. This is generally used with a spring-wire contact, and may be used with or without a battery. Other crystals, such as

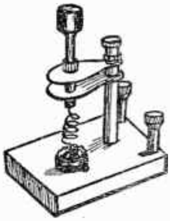


Fig. 180. Spring-Contact Crystal Detector.

Fig. 181. Crystal in Glass Tube.

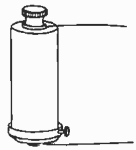


Fig. 182. A Fixed Crystal Detector.

molybdenite, bornite, chalcopyrite, zincite, etc., are occasionally employed for detectors. Trade names are frequently given to various crystals. What appears to be a sensitive grade of iron pyrites is marketed under the name of "Radiocite." Another trade name for practically the same material is "Ferron." Different grades of galena have been called "Lenzite," "Missourite," etc. A detector sold by the name of "Perikon" consists of a zincite crystal (red oxide of zinc), with a contact point of bornite (mixed sulphides of iron and copper). Galena loses its sensitiveness from exposure to air; and all forms of crystals are injured by dust and the oil and perspiration which may be left upon them by the fingers. Scraping lightly with a knife, or washing with ether or alcohol, will improve a dirty crystal. Many crystal detector holders now include a small piece of glass tubing which helps to keep the crystal clean. With the older types of crystal detectors, it is necessary to move the contact point at intervals, as the contact may be disturbed by jarring or "static," and the crystals gradually lose their sensitiveness in certain spots. Later arrangements, known as "fixed crystals," have the sensitive material enclosed in some kind of receptacle, either glass or metal tubing, and a permanent contact made. One make is constructed to fit into the same holder which has been used for the movable contact detector. These fixed crystal detectors vary somewhat in sensitivity. When a good one is obtained it will last a long time without adjustment of any kind. However, when the sensitivity of the device decreases it cannot conveniently be readjusted and must be replaced by a new one. Heat, from soldering, or mounting in Wood's metal, may impair the sensitivity of a crystal detector, and great care must be used when connections are soldered to avoid heating the crystal.

259. The simplest arrangement with which a crystal detector could be used for the reception of signals would be to place the crystal and the head phones in series with the antenna and ground connection. This places the resistance of the phones in the antenna, which is undesirable. In figure 183 the telephones are shunted around the detector, which removes their resistance from the antenna circuit. We then have a divided circuit, with the impedence of the telephone windings on one side and the rectifier on the other. As current from the received signals can only pass through the crystal in one direction, the opposed oscillations accumulate in the antenna circuit, causing an electrostatic charge, which discharges through the telephones at an audio frequency. Of course, this provides for no tuning and would have a decidedly limited usefulness. In figure 184 is shown a simple conductively coupled crystal-detector receiving set, which is used considerably where cheapness and portability are desired. Within a limited range of wave lengths and distance it is quite satisfactory. Galena, iron pyrites, or fused silicon are the preferred crystals for this type of set. A variable condenser may be added, as indicated by the dotted lines. It increases the tuning range of the set. The inductive coupling shown in figure 185 gives greater selectivity. By varying the coupling between the primary and secondary

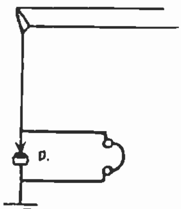
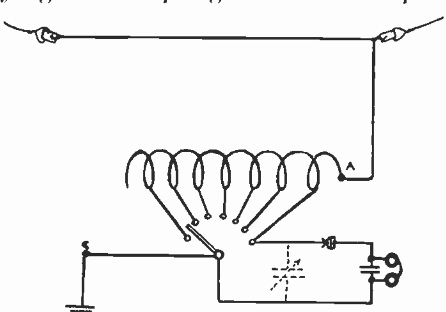


Fig. 183. Simplest Receiving Set.



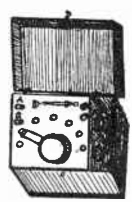


Fig. 184. Conductively Coupled Receiving Set.

coils it is possible to tune out considerable of the interference so annoying in some localities and at certain hours. The receiving coupler varies the inductance, hence the wave length, of both circuits, by the inductive effect between the two coils. In tuning, the two coils are usually placed close together at first. This is known as "close coupling." It gives a broad tuning, which will respond to several wave lengths. When a station is heard, which it is desired to receive, the taps on the primary and secondary coils are roughly adjusted until signals of maximum strength are heard, after which the coupling is loosened, the taps readjusted, and a finer tuning obtained by means of the condensers. With a little experience in manipulating the movable-coil transformer one learns to "tune in" the desired stations, and to eliminate the undesired signals. Atmospheric disturbances may also be reduced somewhat by adjustment of the coupling.

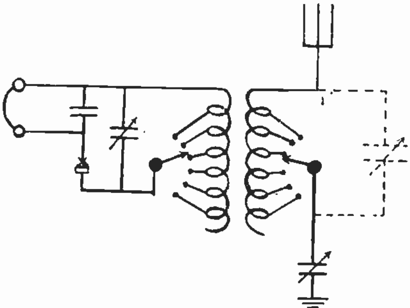


Fig. 185. Diagram of Inductively Coupled Receiver.

260. When electromagnetic waves are intercepted by the receiving antenna the radio-frequency vibrations, whether caused by continuous or damped waves, cause corresponding reversals of direction in the energy set up in the antenna circuit so that we have a high-frequency alternating current in that circuit. This is *rectified* to a one-way pulsating current by the detector, and the one way pulsations are then sent through the windings of the receiving telephones. If the intercepted waves are continuous, the first wave will attract the telephone diaphragm and it will remain there until released by discontinuing the signals. Continuous waves will not operate the telephone diaphragm unless broken

up in some manner. With damped waves, from a "spark transmitter," the wave trains of gradually dying out amplitude actuate the telephone diaphragm without modulating or interrupting device; and *there is one click in the telephone for each complete train of waves.* For some reason, there has been an impression among students of radio that the detector reduces the signals to audio frequency. *All that the crystal detector does is to rectify the radio-frequency alternating current into one-way pulsating current. The*

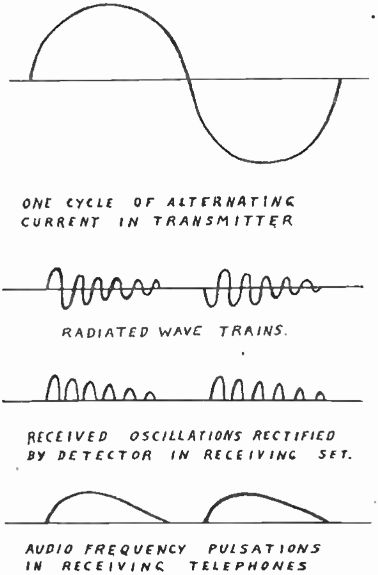


Fig. 186. Illustration of the Reception of Two Damped Wave Trains.

first pulsation attracts the telephone diaphragm, and the succeeding pulsations of the wave train follow each other so rapidly that the physical inertia of the instrument does not permit of the diaphragm being released until the last wave train of radio frequency has passed through the windings. It is this action of the telephone receiver, when employed with a crystal detector, which reproduces the sound waves emitted by the transmitter. While it is possible that the telephone diaphragm may respond slightly to the radio-frequency pulsations as well as to the audio-frequency variations, of course the former would pass unnoticed on account of being inaudible. There is one movement of the diaphragm for each wave train, and *for each alternation in the power circuit of the transmitter*. Hence, the number of alternations in that circuit is called the *audio frequency of the transmitter*. A 500-cycle transmitter will cause 1000 clicks per second in the distant receiving telephone. *Nothing has passed between the two stations but electrical impulses, and the sound heard in the telephones comes solely from the "rattling" of the diaphragm, under the influence of the variations in magnetic attraction caused by the energy picked up by the receiving station when the transmitted electromagnetic waves impinge upon the receiving antenna.*

261. Condensers are used in different ways in receiving apparatus, according to the effect desired. Placed across the secondary, as in figure 185, a condenser with one set of fixed plates and another set of movable plates gives a degree of resonant tuning, with a slight addition to the natural period of the circuit, or wave length, which can be offset by other means if desired. A condenser in series with the antenna, as in figure 185, can be used to tune the antenna to a shorter wave length than its fundamental. This operates in the same way whether applied to a receiving or transmitting antenna, being an application of the law of condensers in series, the other condenser in this case being, of course, the capacity between the antenna and the ground. When a condenser is placed in parallel to the antenna circuit, as indicated by the dotted lines in figure 185, a longer wave length may be obtained than is provided by the antenna circuit and inductance coil. Condensers used for these

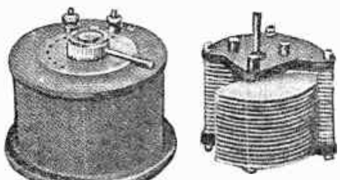


Fig. 187. Variable Condenser.

purposes in receiving sets have usually a capacity of from .00025 to .0005 microfarads, with the movable plates rotated inside the stationary plates. This is decreased as the movable and stationary plates are separated. The rotating plates of a condenser should be connected to the grounded side of a receiving circuit, to give best results. A switching arrangement, as shown in figure 188, is sometimes employed for the purpose of making one condenser provide both short and long wave tuning. This may be connected to the primary of the two-circuit coupler, or to a single-coil receiver. With the switch arms standing as shown in the illustration, it can

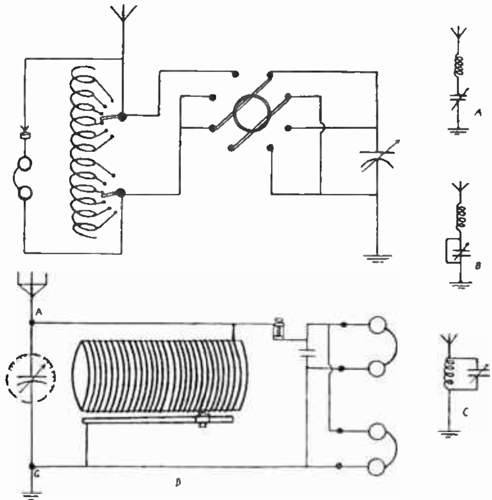


Fig. 188. Capacity-Changing Switch and Modern Crystal-Detector Receiving Set.

be seen that the antenna condenser is directly in series with the coil, as in a. When the blades are turned clockwise, to the next position, the condenser is connected as b, or shorted out of the circuit. With the switch blades in the next position, the condenser is connected in parallel, as in c.

At D, figure 188, is shown an arrangement which has proved surprisingly effective in clear reception over somewhat greater distances than are usually expected of a simple crystal-detector apparatus. The coil consists of about 75 turns of No. 16 enameled copper wire, wound over a bakelite tubing 5 inches in diameter and seven inches long. Fine, stout, twine is wound between the wires to make even spacing and to reduce capacity effects between the turns of the wire. The twine is smaller in diameter than the wire so that it can be left in place and permit contact by the movable portion of a bar slider, eliminating the taps generally used with crystal-detector receiving sets. The condenser may be permanently connected as shown at D, or through a capacity-changing switch.*

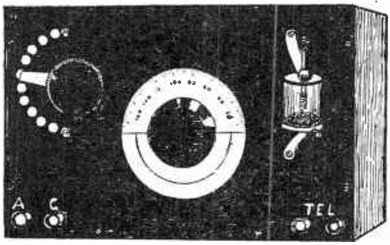


Fig. 189. Typical Conductively Coupled Crystal-Detector Receiving Set.†

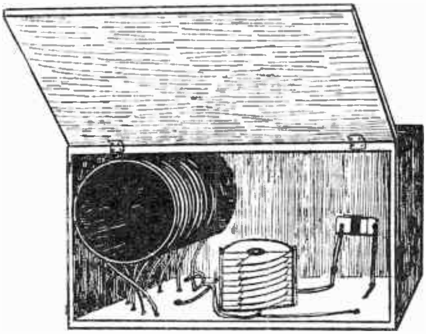
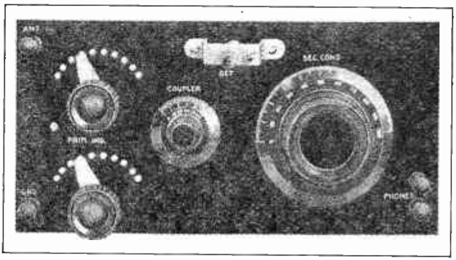


Fig. 190. Interior of Above Receiver.

*Note—A beautiful receiver following this plan has been duplicated many times in the laboratory of the author. A 23-plate variable condenser is used, the dial for turning the shaft being located at the left side of a 7x12 bakelite panel. The rod and slider are then fastened at the right side of the panel, a horizontal slit being cut for accommodating the bar flush with the surface of the panel and with room enough each side of it for the slider to be moved along. Large nickel washers over the edge of the slit, at front and back of the panel, hold the bar in place. The screws accomplishing this are long enough to go through the bakelite tubing, and also serve to hold this in the right position for contact with the slider. A Foote adjustable crystal detector is used. This consists of a piece of iron pyrites enclosed in fiber tubing, with a strong spiral contact spring, which can be set in position with a lock nut.

†The receiving set illustrated in figures 189 and 190 was home-made and proved successful for broadcast reception. A silicon detector was mounted in a glass detector holder and attached to the front of the bakelite panel. The coil consisted of silk-covered No. 22 copper wire, 113 turns, on a bakelite tube 3 inches in diameter and 6 inches long. Ten taps were made, the first one at the eighteenth turn, then five taps, including eleven turns each, then taps giving turns of 8, 7 and 6 turns, respectively. The telephone condenser was home-made, of two pieces of copper shim, 1 by 2 inches, with a piece of mica between them and held together with "friction tape." A good 23-plate variable condenser was used.

A condenser, of small size and fixed capacity, generally made of two or three small pieces of tin foil or copper shim, with waxed paper or mica dielectric, is frequently placed across the telephone connections, and generally increases the volume of the signals heard. This condenser stores up a small charge of energy with each radio-frequency alternation passing in one direction through the telephone windings, and liberates this charge at the instant when the detector is stopping the other half from passing through it. As this discharge is in the same direction as the alternation that has just been passed to the telephones by the detector, the magnifying effect can be understood. This condenser usually has a capacity of about .001 mfd. An additional inductance, known as a *loading coil,* is sometimes used in series with the antenna, for obtaining longer wave lengths than provided for in the coupler, but this is not done so much as formerly. A capacity-coupled receiving set, such as illustrated in figure 193, has been used in the U. S. Navy. The



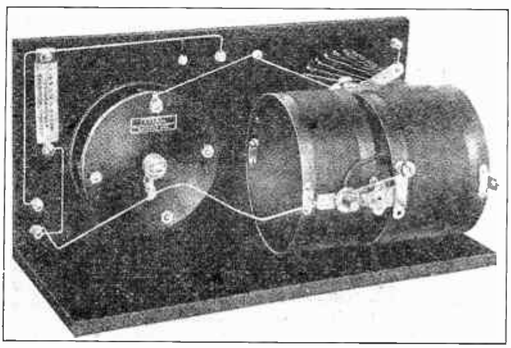


Fig. 191. Front View and Interior of a Variocoupler Crystal-Detector. Receiving Set. (Federal Telephone and Telegraph Co.)

primary and secondary coils are fixed permanently at right angles to prevent inductive coupling between them, and

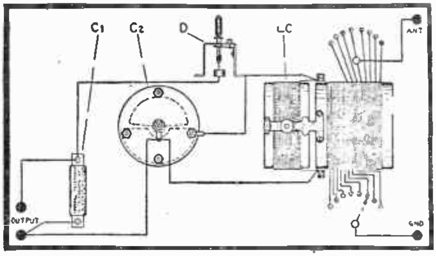


Fig. 192. Diagram of Receiver Illustrated in Fig. 191.

"electrostatic" coupling is accomplished by use of two coupling condensers. These are generally mounted on a common shaft, so that the plates are both rotated by the turning of a single handle. The principle advantage of this type of receiver is its compactness. The coils are usually of the flat variety, taking up much less room than the tube-wound inductances.

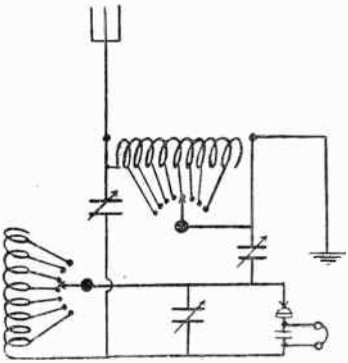


Fig. 193. Capacity-Coupled Receiving Circuit.

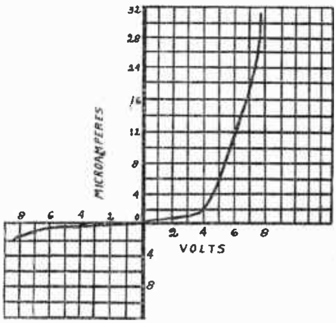


Fig. 194. Characteristic Curve of Carborundum Detector.

262. The *carborundum detector* does not operate successfully without a local battery current. This is sometimes called a "booster battery." Other contact detectors are generally sufficiently sensitive for use in receiving circuits without battery current. The carborundum, especially, has the property of being considerably more conductive at certain voltages than at others, in addition to its unilateral conductivity. This may be determined by making a characteristic

curve of a piece of carborundum, showing the amount of current which passes through the crystal with the same voltage applied first in one direction and then in the other, and repeating the test at different voltages. By placing a small ammeter and voltmeter in circuit with the crystal, as in figure 195, a convenient arrangement is provided for testing its conductivity. A double-pole double-throw switch is wired as shown, so that the polarity of the battery current in the detector circuit is changed by throwing the switch. The voltage is varied by the potentiometer. With this set at a certain voltage, throwing the switch in opposite directions will indicate the best conductivity of the crystal by the relative values of the ammeter readings. The curve made from these readings will show the sensitiveness of the crystal. The curve should rise sharply from the bend at which the sensitiveness starts, if the crystal is a good one. As the incoming signals consist of oscillations alternating between positive and negative, either all of the positive or all of the negative oscillations will pass through the crystal, according to its direction of best conductivity.

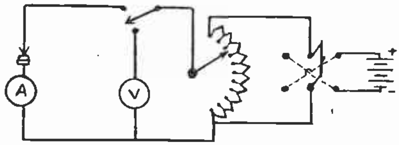


Fig. 195. Method of Testing Carborundum.

263. When an inductance coil is tapped, there is a capacity in the end of the coil not in use. This is often called a "dead end" effect. A certain portion of the high-fre-

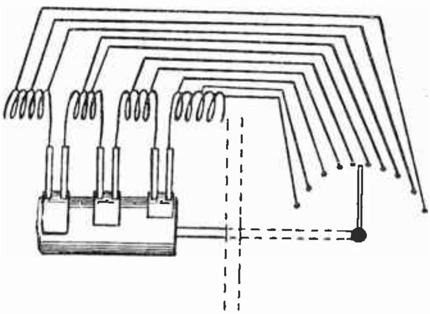


Fig. 196. End-Turn Switch.

quency current will oscillate in this dead end of the coil, and reduce the volume of the sounds heard in the telephones just that much. In the larger commercial types of crystal-detector receiving apparatus this is usually overcome by the use of a special kind of switch, which automatically disconnects sections of the coil as they are tuned out of the circuit.

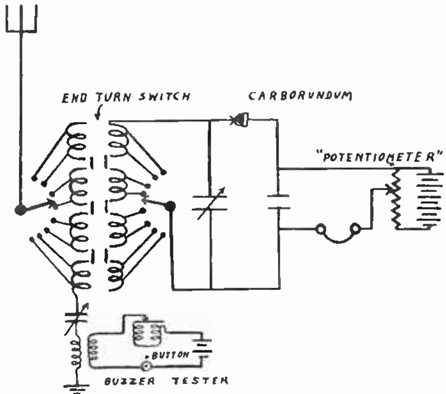


Fig. 197. Carborundum-Detector Receiving Apparatus Equipped with a Buzzer Tester Inductively Coupled.

A convenience in operating a crystal-detector receiving set is a *buzzer tester*. This consists of a small buzzer with a battery and push-button. It may be *inductively* coupled, as in figure 197, or the buzzer may be connected *unilaterally*, as in figure 198, or as shown in figure 199. By sending the

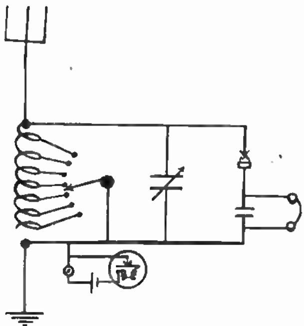


Fig. 198. Unilaterally Connected Buzzer Tester.

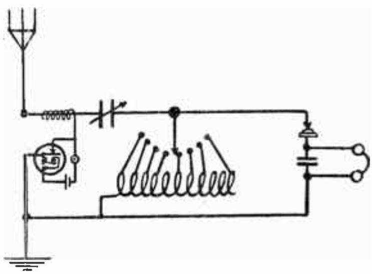


Fig. 199. Single-Circuit Receiver With Galena or Fused-Silicon Detector and Buzzer-Tester.

feeble oscillations generated by the buzzer through the antenna circuit, it is caused to vibrate at near its own fundamental wave length; and this energy passes through the receiving circuits, reproducing the sound of the buzzer in the receiving telephones when the circuit and the detector are properly adjusted. This is a great advantage, for it is possible to locate any open in the circuit, such as a loose connection, a broken telephone cord, etc., as well as to set the detector for the most sensitive spot preparatory to "listening in" for signals.

A buzzer and small flash-light battery may be mounted in a small separate box, with one wire leading out of the box to be attached to the antenna or ground binding post of crystal detector receiving sets, as shown in figure 198.

264. In figure 197, it will be noticed, there is a *"potentiometer"* placed between the batteries and the receiving circuit. It can be seen that this differs from a rheostat in that both ends are connected to the circuit. Strictly speaking, this device is not a potentiometer, and is not measuring anything (See chapter 38). It is in reality performing as a *"voltage divider,"* on the principle of Ohm's law that *volts dropped* in overcoming resistance are equal to $R \times I$. With approximately the same current flowing in the battery circuit, it is possible to obtain various voltages by tapping the resistance coil in different places. The term potentiometer, however, is quite generally used in referring to this type of resistance.

265. The crystal-detector receiving set has been overshadowed by the popularity of the vacuum-tube apparatus. But for local reception the vacuum-tube *detector* has no advantage over a good sensitive crystal, except that there is no "cat whisker" to adjust. It is, however, possible to employ vacuum tubes in amplifying circuits, and to increase the volume of the received signals, in ways not possible with the crystals. Some modern receivers combine a crystal detector with vacuum-tube amplifying arrangements, thus taking advantage of the clarity of the crystal detector and the increased distance range and volume obtainable from

the tube amplifiers. At sea, when vacuum-tube receivers are used, it is customary to have on hand an emergency receiver equipped with a crystal detector, for a large supply of good crystals can be carried at small expense, and vacuum tubes are expensive and perishable. Many of the crystal-detector receiving sets now on the market are designed for home use. In many of these compactness is gained by the use of a "variocoupler." In this the secondary, instead of sliding in and out of the primary of the transformer, is rotated on a shaft with slipping contacts, and induction between the two coils is varied by the different angles of the rotor. The rotor has no taps, the tuning in the secondary circuit being accomplished with the condenser only.

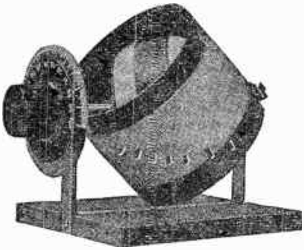


Fig. 200. Variocoupler.

266. Various attempts at producing amplifiers for use with crystal detectors, without the use of vacuum tubes, have been made. None has yet been commercially adopted in this country, although a magnetic amplifier invented by S. G. Brown of London has been used by the English Marconi Company for some time. It is claimed that this apparatus is proving successful in magnifying the strength of the signals, can be operated in "cascade" fashion, as are vacuum-tube amplifying circuits, and that with further development, this may "make the crystal perform as majestically as the vacuum tube itself." (The Literary Digest, January 27, 1923, contained an account of this, with a photograph). In its simpler form, the Brown relay consists of a horseshoe permanent magnet, which has soft iron poles attached to the ends, to be used as electromagnets. This is connected in the secondary of the receiving circuit as shown in figure 201. A vibrating reed, or diaphragm, is placed at the end of the magnet, and connected in series with a battery of from 2 to 6 volts and the telephones. The diaphragm can be adjusted to synchronism with the frequency of the received signals. The make and break contact points in the telephone circuit consist of two buttons of carbon. The vibration of the relay diaphragm increases the force of the vibrations of the telephone diaphragm, on account of the addition of the battery current to the energy of the received

signals. A more sensitive type of this device is equipped with a carbon granule microphone, connected as shown in figure 202. Mr. Brown has since invented a loud speaker

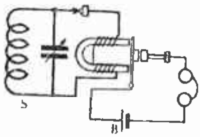


Fig. 201. Brown Microphonic Relay.

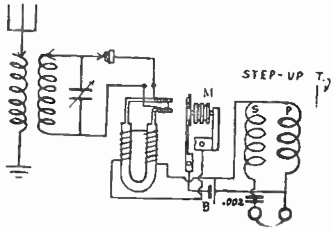


Fig. 202. Improved Brown Microphone Relay.

to operate on a crystal detector. The accompanying information regarding this loud speaker is quoted from the *Radio News* of March, 1924. "An ordinary Brown telephone receiver A, with adjustable magnets, is attached to a metal arm pivoted at B, and weighted at the end with counter-balance C. To the reed F and the receiver are attached the steel needle E to whose end is fastened a small disk F covered on the bottom with cork. This small disk is directly above a perfectly level glass plate G. The glass plate, in turn, is mounted on the shaft of a phonograph motor so that it may be slowly revolved. The disc F, as

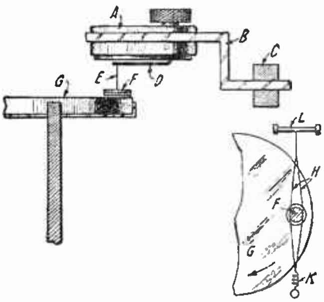


Fig. 203. Working Parts of the Brown Crystal-Detector Loud Speaker, Known as the Frenophone.

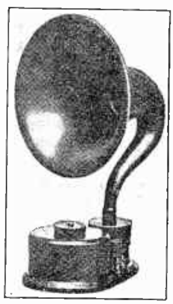


Fig. 204. The Brown Frenophone.

shown, is suspended by threads H near the edge of the glass plate G. The two threads terminate at the center of the diaphragm L which is the diaphragm of the loud speaker.

In operation, the weight of the phone receiver brings the cork-faced steel disk into contact with the revolving glass plate. When the signals are picked up, the reed F vibrates in unison with the receiver diaphragm, thus creating an upward and downward motion of the disc F. The pressure of the needle on the disc can be adjusted by moving the counter-balance C. In operation, the motor is started, revolving the glass plate. Signals are tuned in causing the diaphragm reed and needle to vibrate. This produces a pressure between the disc and glass plate. As the former is not rigidly fixed, it drags according to the pressure upon it. This is communicated to the diaphragm L, causing it to vibrate in unison producing sounds in the loud speaker horn. Cork and glass have a high friction coefficient, and for this reason the action is greatly magnified."

Crystal-detector amplifying circuits have been achieved, in an experimental way, by the use of zincite crystals and steel contact points, the electrical principle involved being that of producing a "negative resistance," or an artificially created resistance which neutralizes the usual resistance of the circuit.*

267. Where a loud speaker is not available, it is usually desirable to use more than one pair of head phones with the crystal-detector receiver. The resistance of the phones, and of the antenna and receiving set, will determine whether it is best to connect these in series with each other or in parallel. A little experimenting will soon tell. Generally two pairs of phones will give best results when connected in parallel with each other, working on the law of parallel resistance, and offering a greater conductivity than if connected in series. However, if four or six phones are used, it is best to connect them in series parallel, with two phones in series in each of the parallel groups. The simplest method of accomplishing a connection of several pairs of phones to a receiver which has binding posts for the phone connection is to use two good wire springs, about two inches long and one half-inch in diameter. The end of each spring is put into the hole in the binding post made for the telephone tips, and the springs stand out from the posts, parallel to each other. The tips of the telephone cords may then be pressed down into the springs.

*See *Radio News*, September, October and November, 1924. Also January, 1927, for zincite microphone.

CHAPTER 30

The Receiving Antenna

Antenna Materials — Types of Receiving Antennæ — Lightning Arrester — Beverage Antenna—Directional Factor—Fundamental Wave Length

268. Some form of elevated antenna is usually necessary for reception with a crystal-detector receiving set, if used without amplifiers of any kind, and will give greater range on a vacuum-tube receiver than a loop. The higher this antenna the greater will be its distance range. The antenna must be grounded. The ground may consist of metal plates, or an iron pipe, buried four or five feet in the earth, preferably moist earth, or the ground connection of the receiving set may be attached to a water pipe or radiator in the building in which the receiving apparatus is installed. If this is done a good, tight connection must be made, and the radiator or water pipe must be clean and free from paint or rust. Sometimes two or three grounds to different points will increase the volume of the signals, by reducing the resistance at the base of the antenna. It is difficult to solder the wire to an iron pipe, so a clamp made for this purpose is convenient. A single wire is sometimes used for a receiving antenna. While this is somewhat more selective than an antenna consisting of two or more wires, the advantage of this is offset by the greater amount of energy picked up when more wires are used. Probably the receiving antenna which has proved most satisfactory, all around, consists of two or three parallel wires from 75 to 100 feet long, spaced from two to three feet apart. Increasing the spacing between the wires increases the capacity of the antenna, but this increase is less noticeable beyond the three-foot spacing. Best results are obtained when the "far end" is bridged with wire, as shown in figure 205. A "V"-shaped antenna, such as shown in figure 206, is sometimes more convenient, and will often prove satisfactory. The material of which the antenna is constructed affects its efficiency and durability. Number 14 bare copper wire is the commonest conductor. It may be solid or stranded. Solid enameled copper wire of size number 14 or 12 is also frequently used. The enamel prevents the corrosion which so soon attacks the bare wire, increasing the resistance and decreasing the efficiency of the antenna. Weather proofed rubber insulated wire, such as used on ordinary power lines, makes an excel-

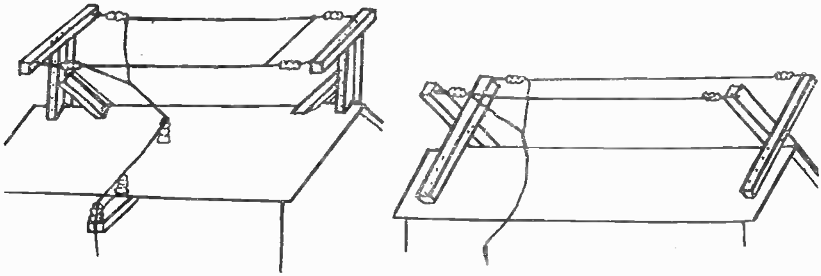


Fig. 205. Housetop Antennae.

lent antenna and remains in good condition longer than most types if the joints are properly protected. If a single wire antenna is used, the lead-in and elevated portion may be made continuous so that no soldered joints are necessary, and possibility of corrosion reduced to a minimum. Flat "ribbons" of copper or bronze are sometimes used, and give excellent results. Some beautiful looking and highly efficient antenna insulators are made of pyrex, and may be obtained in a variety of shapes.

269. The National Board of Fire Underwriters permits the use of a lightning arrester, in the form of a small safety gap, or evacuated receptacle containing metal filings, in place of the regulation lightning switch, when the antenna is installed for receiving only. The gap is of such a resistance that strong current, such as lightning, or that from a high-powered station in the immediate vicinity of the receiver, will jump the gap and follow the wire, seeking the path of least resistance to the ground, but a weaker current, such as received signals, will not jump the gap on account of its resistance. Sometimes this gap is used in connection with the lightning switch, to protect the receiving apparatus from injury from too high power, when very near to a high-powered transmitting station, or possible lightning damage when the switch is in the receiving position.

The antenna must be as far as possible from other wires, such as power lines, telephones, etc., both to avoid induction from them which may make objectionable noises in the receiving telephones, and to avoid danger. There have been some serious accidents due to antennæ coming in contact with live power lines. Neither should the wires of the antenna come in contact with branches of trees, as these are conductors to the earth, and will rob the antenna of its

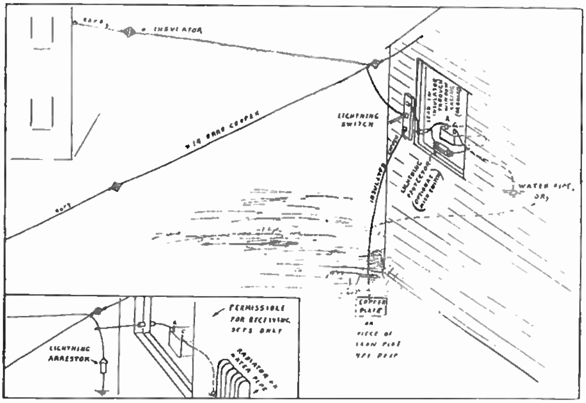


Fig. 206. Arrangement of V Antenna for a Home Receiving Set.

energy, making the signals weak or perhaps entirely inaudible.

270. Types of antennæ used for receiving vary more than those used for transmitting, as there are many receiving antennæ which would not handle sufficient current for transmitting to any distance. The receiver may make use of the same antenna that is used for transmitting, by connection at the antenna change-over switch. This is the method generally employed on board ship, and to some extent in commercial land stations. The large transoceanic stations, however, generally have separate antennæ for transmitting and receiving, these being located several miles apart. The umbrella, fan, T and inverted L types described in connection with transmitting apparatus may each be employed for receiving, but the T and inverted L are most often used. Loop antennæ, which are popular with vacuum-tube amplifying apparatus, are not efficient with crystal-detector receivers, as they do not pick up sufficient energy to operate this type of apparatus successfully, under normal conditions.

The antenna which will receive most uniformly from all directions is an umbrella, or modification of this. As it requires less space than the elongated types, it is especially suited for installation on roofs of small houses, etc. A condenser type of antenna, using a counterpoise instead of direct ground, with both antenna and counterpoise made of a network of heavy wire or copper strips, is also useful for obtaining volume in reception within a limited space, particularly where it is difficult to obtain a good ground connection. The counterpoise grounds the antenna statically.

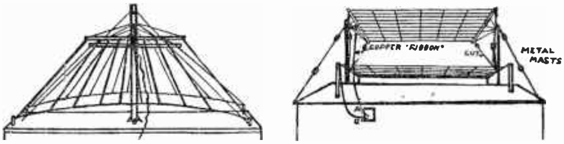


Fig. 207. Efficient Antennae for Limited Space.

271. Many novel devices have been used for receiving antenna, by scientists in experimental ways, and by amateurs as makeshifts. While these objects are not to be taken seriously as standard radio equipment, they are interesting evidence of the persistency of the radiated waves. Dr. J. A. Fleming, in his *Elementary Manual of Radiotelegraphy,* records the use of an insulated iron bedstead, and of a zinc dust pan. He states that "these signals are much weaker than when a high elevated receiving antenna is attached, but the fact that they can be received at all seems to indicate that mechanism by means of which they are transmitted is not wholly an electric space wave in the ether, but partly of the nature of a surface wave of potential transmitted along the earth's surface materials." In an effort to dispense with the standard type of elevated antenna, a plug for utilizing the wiring of electric lighting systems has been devised. It contains a condenser to prevent short-circuiting the lighting system. Under certain conditions fairly good results have been obtained with these. In cities a connection to the gas pipe usually brings in local signals. Small coils of wire wound on pasteboard tubing have been used in connection with sensitive vacuum-tube receiving apparatus, by General Squiers. One of these he nicknamed a "rolling-pin antenna." (See *Collier's Weekly,* April 8, 1922.)

272. The directional factor affects the usefulness of receiving antennæ. Speaking generally, it may be said that an antenna will respond most readily to vibrations of the same period which it would radiate if it were used for transmitting, and that it will have a directional characteristic for receiving exactly corresponding to its directional characteristic in transmitting. An inverted L antenna will receive signals from a greater distance when they are coming

in a direction which causes them to strike the lead-in end of the antenna first, and this antenna will radiate to a greater distance from the lead-in end. Also, their range will be the best if they are at exactly the same height above the ground. A single wire directional antenna has been patented by Mr. H. H. Beverage, and is known as the Beverage antenna. This consists of a wire exactly the length of the wave length of the signals which it is desired to receive, or a multiple of this, and the "far end" is grounded through a resistance of the same value as the impedence of the horizontal wire when installed. With an antenna 10 feet high, and a line of No. 16 bare copper, this would be approximately three or four hundred ohms, for a wire 650 feet long, with a wave length of about 200 meters. (See QST, November, 1922.)

A recent development in receiving antennæ is a polished metal sphere about one foot in diameter, mounted at the top of a long pole, and with a lead-in attached. This is non-directional, has a wide range of wave lengths, and appears to have the effect of reducing some of the noise produced by static. Some predict that these spheres, neatly mounted in rows and at the same height, will solve the apartment-house antenna problem of the future.

273. In installing a horizontal antenna, the wave lengths on which it is to be used are to be considered. A wire 100 feet long 50 feet high gives a fundamental wave length of about 205 meters, which allows for the additional inductance and capacity of the receiving set to be used in obtaining the broadcast wave length. The fundamental wave length of an antenna is found to be approximately its length multiplied by 4½. Hence, to arrive at the fundamental wave length of an antenna to be installed, the following rule will apply:

$$\text{Wave length in meters} = \frac{(\text{height in feet plus horizontal length in feet}) \times 4.5}{3.28}$$

A short cut, avoiding one step in the arithmetic, is to add the height from the ground, in feet, to the horizontal length in feet, and simply multiply this sum by 1.37. The smaller and more limited in tuning range is the receiving set, the nearer must the fundamental of the antenna system approach the wave length of the signals which it is desired to receive.

PART THREE

VACUUM TUBES AND CONTINUOUS WAVES

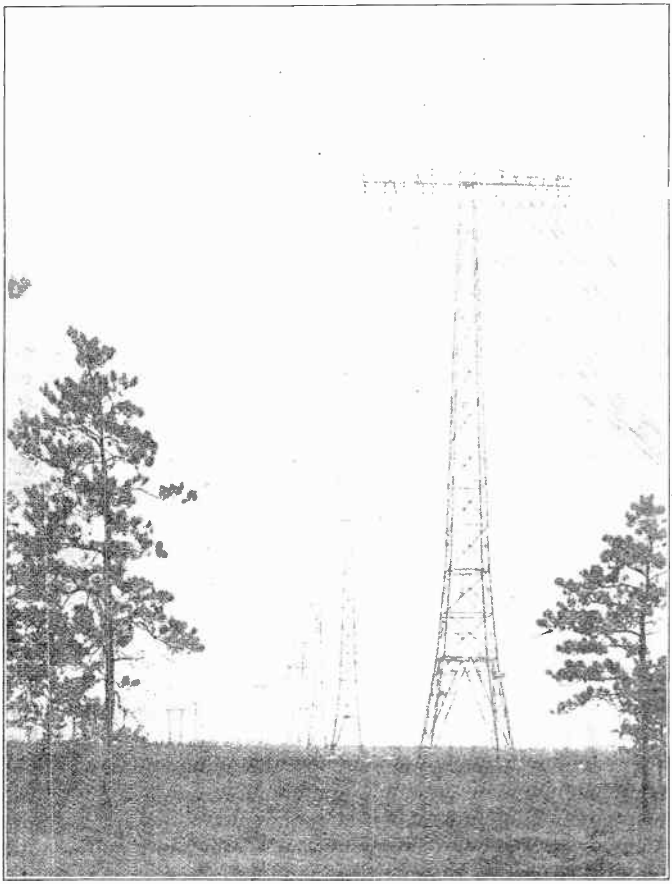


Fig. 208. "Sentinels of World Wide Wireless," three miles of antenna, used for continuous-wave transmission at Radio Central, the high-powered station of the Radio Corporation of America, at Rocky Point, Long Island, WQK and WQL.

CHAPTER 31

The Arc and the High-Frequency Alternator

Continuous Waves—Alexanderson Alternator—Radio Central—Goldschmidt Alternator—Schmidt Alternator—Frequency-Doubling Transformer—Timed-Spark Transmitter—Arc Transmitter, Theory and Stations—Rules for Starting Arc Transmitter—Stations LY, WVB, NSS, WQK, WQL, WXY and 2XF.

274. *Continuous waves* have many advantages over damped waves, for the receiving station. They do not decrease in amplitude as do damped waves, but are sustained, holding practically the same amplitude for the duration of the key pressure. *They are confined to one wave length,*

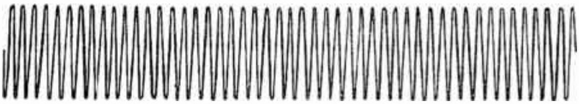


Fig. 209. Continuous Waves.

and cause little interference, are not absorbed to any great extent while passing through space, and hence have a greater range for a given power; and the pitch of the signals is under the control of the operator at the receiving station, where varied tuning may vary the tone of the signals. Elec-

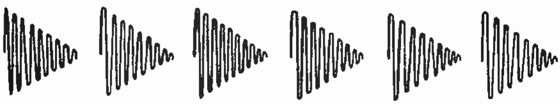


Fig. 210. Damped Waves.

tromagnetic waves of continuous amplitude are radiated from an antenna which is energized by *high-frequency alternating current of continuous amplitude.*

275. The development of vacuum-tube receivers, and the fact that they are the first satisfactory method devised for receiving continuous waves, has led to renewed interest in some of the older forms of continuous-wave transmitters, and also to the invention of transmitters in which the tubes themselves are the source of oscillations. Lauer and Brown's *Radio Engineering Principles* states the following regarding continuous waves for transmitting and receiving:

"A receiving circuit will respond with greatest amplitude to a transmitting circuit when it is tuned to the latter. The sharpness of tuning, as evidenced by the abruptness or steepness of the peak of the resonance curve, is a direct function of the decrement of the wave, and the smaller the decrement, the sharper will be the tuning. A logical conclusion is then that exceedingly sharp tuning will be obtained with oscillations having zero decrement, that is, with undamped oscillations. Damped oscillations require setting up in the antenna circuit considerably greater voltages and currents than undamped oscillations. This in turn necessitates better insulation of the antenna, conductors of larger cross section, and apparatus of greater power output. The advantage of undamped waves is then obvious. *It consists essentially in using low power apparatus continuously rather than high power apparatus intermittently.*"

Any method for generating alternating current of high frequency may be used for the transmission of undamped waves; and there are a number of different types of apparatus in use for this purpose, among which are the high-frequency alternator, the arc converter, and the vacuum-tube oscillator. There is also a system of producing waves which are practically continuous; by what is known as the timed-spark method.

276. The best known high-frequency alternator is the *Alexanderson* which was developed by Fessenden from designs originated by E. F. Alexanderson, and is manufac-

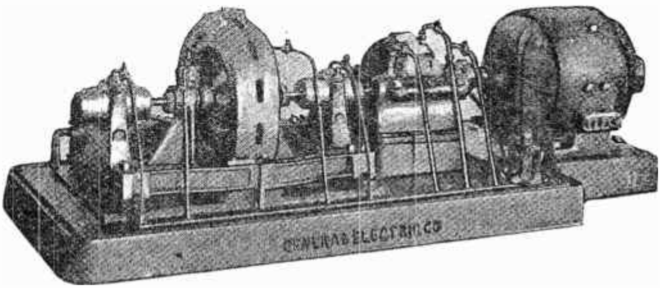


Fig. 211. 200-K. W. 100,000-Cycle Alexanderson Alternator.

tured by the General Electric Company. The machine is based on the principle of the low-frequency inductor alternator, which was described in paragraph 90, but it has a great many times the number of "teeth"—generally about 300. These are not cut on the edge of the rotor, as in the low-frequency machine, but consist of openings a short distance from the edge, leaving the periphery smooth and solid, which reduces friction. These slots are then filled with phosphor bronze, or other non-magnetic material. The field coil is wound over a continuous iron core, through which the magnetic lines of force pass; and the armature is arranged in a wave-shaped winding, and mounted on the inside of the case in such a manner that the rotor cuts through the magnetic flux (see figure 58). As the rotor moves through the magnetic flux the magnetic reluctance is increased and decreased for each time that the conducting steel and the non-magnetic phosphor-bronze pass a given point; and the E. M. F. induced into the armature coils varies periodically, with a frequency equal to the product of the number of slots in the rotor and the speed of rotation. In the Proceedings of the Institute of Radio Engineers, August, 1920, there was a description of the high frequency alternator installation at the New Brunswick Naval station, by the inventor. Mr. Alexanderson says, "The 200 kilowatt alternator when operated at the New Brunswick wave length of 13,600 meters runs at a speed of 2,170 r.p.m. It is driven by an induction motor through a gear of a ratio of 2.97:1. When the radio-frequency alternator is used as a source of radiation, the wave length is determined directly by the rotative speed of the machine. Thus obviously, it is important that the rotative speed of the machine should be as nearly absolutely constant as it is possible to make it. An important accessory of the alternator set is therefore the speed regulator."

277. The *Alexanderson alternator* may be used with the simplest kind of a circuit, sometimes being connected directly in series with the antenna and the ground, with the key in series in the d.c. field supply. However, where more power is used this is not practical, and the key is usually operated through a *magnetic modulator,* called by the inventor a magnetic amplifier. This may be seen in figure 212. The magnetic device consists of two coils wound over separate legs of a double-cored laminated transformer, and connected in circuit with a coil which is inductively coupled to the secondary of an oscillation transformer. Resonance is obtained by the condensers. Around the two iron-cored

coils a larger coil is wound, this being connected in series with the key and a battery. The period of the circuit containing the coils and condensers is adjusted so that when the key contact is closed, with the disc raised as in Fig. 212, most of the energy is absorbed, preventing radiation: but when the key is pressed, this circuit is thrown out of resonance, and the continuous waves produced by the alternator are radiated from the antenna. The current supplied by the alternator is of extremely high voltage as well as of high frequency. To secure the high frequency the disc is revolved at terrific speed, several miles per minute. The armature, in the high-powered apparatus, consists of 64 sepa-

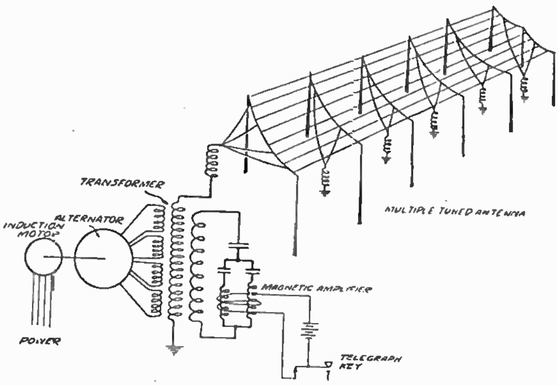


Fig. 212. Circuits of 200-K. W. Alexanderson Alternator.

rate coils, each connected to a separate set of windings making up the primary of the oscillation transformer. This is done so that in case a section of the armature should be damaged, the apparatus could still be operated without inconvenience. One of the sections of the armature, instead of being used for the oscillation transformer, is connected in such a manner that it constitutes a choke coil for the motor speed regulation. While the apparatus is large and of great power, it is at the same time sensitive, and can be controlled with a very few devices. The motor speed and the wave length are regulated by means of a single switch.

278. Alexanderson alternators are installed at Radio Central on Long Island. This comprises three branches, or points of operation. The "super station," where the alternators are

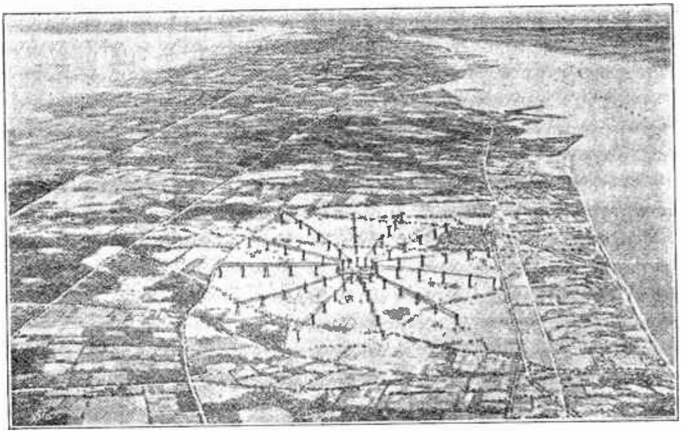


Fig. 213. Radio Central, WQK and WQL.

housed, covers 6,400 acres. It is equipped with twelve antenna units, supported by seventy-two steel towers, and ten Alexanderson alternators with a power output of 2,000 kilowatts, or 2,700 H. P. The *antcnna* is of the *multiple-tuned*

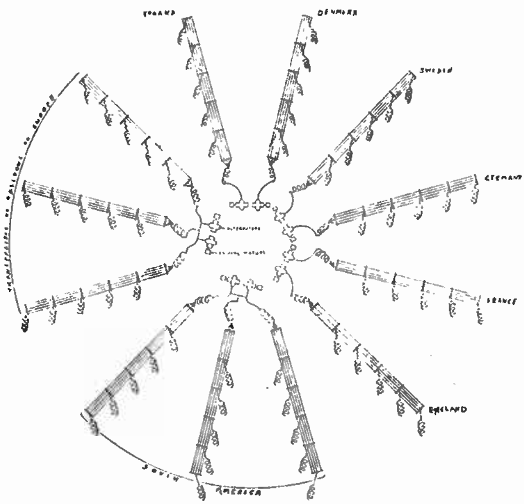


Fig. 214. Antenna Combinations at Radio Central, consisting of Twelve Antenna Units with Eight Possible Combinations.

type, being grounded at intervals through inductance coils, which are used to tune the individual sections to the required wave length to be in synchronism with the current supplied by the alternator. These coils are about 6 feet in diameter, consisting of between 600 and 700 strands of No. 30 enameled copper wire, and supported by porcelain tubes and blocks. The outsides are protected from the weather by suitable coverings of varnished cambric and treated braid. Their inductance is about 19 millihenries. The multiple tuning is used to reduce antenna resistance, the effect being that of connecting resistances in parallel. The receiving station is located sixteen miles away, at Riverhead; and there is a centralized control station at the Broad street office in New York, seventy miles away, where all messages are sent by remote control, or received by automatic relays.

The Alexanderson Transmitters at Rocky Point are not employed for communication with ships at sea, but are used exclusively for Transatlantic communication. The system working Germany only is known by the call letters WQK, and operates on 15,465 meters. WQL, on 17,500 meters, communicates with Germany and Italy. The RCA station operating on commercial wave lengths, and communicating with ships, is called WNY, and is at New York. A short-wave station, 2XF, is also maintained at Rocky Point for

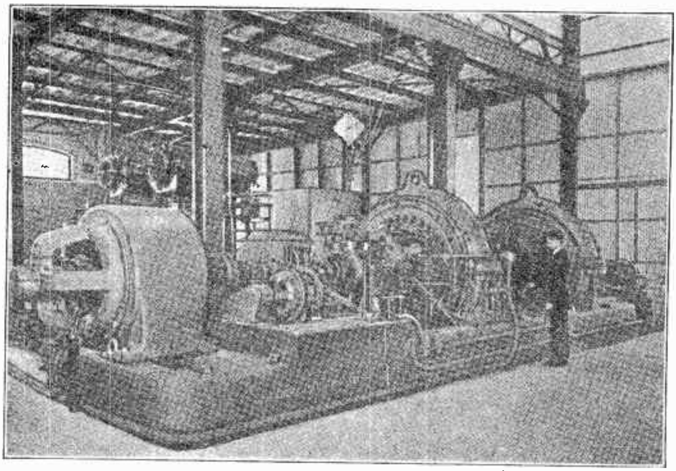


Fig. 215. Two of the Alternators at Radio Central.

communication with Argentina. It has been found more successful for working this particular route through static than the longer wave lengths.

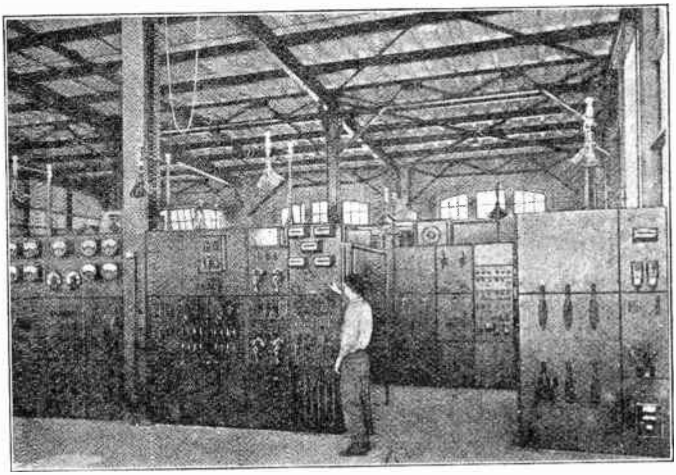


Fig. 216. Main Switch Boards at Radio Central.
("Arranged, Left to Right, are Voltage Regulators, Compensating Control, Magnetic-Amplifier Control, Telegraph Control and Main Power-Supply Panels.")

279. The *Goldschmidt Alternator* is constructed on the same principle as the ordinary generator, but with the current taken from the field winding instead of from the arma-

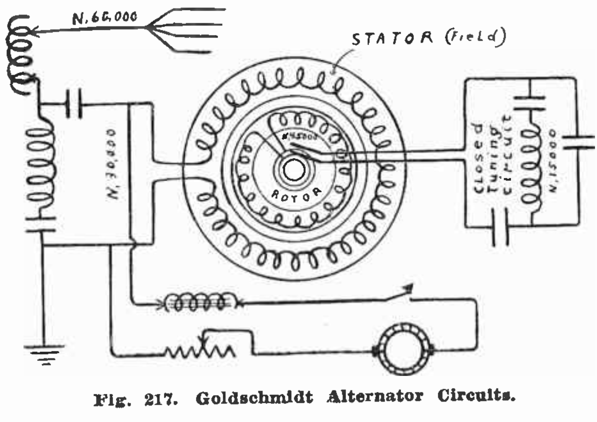


Fig. 217. Goldschmidt Alternator Circuits.

ture. By employing the principle of resonance, a comparatively low-frequency current is stepped up several times in number of vibrations. This is known as the *reflection* system. In figure 217 it will be seen that the motor-driven rotor has connected to it, by means of slip rings, what amounts to a short-circuiting device. In this circuit are connected a coil and condensers for tuning purposes; and by means of the tuning facilities provided in the rotor and stator circuits, a condition of resonance is maintained, which assures the greatest possible induction between the two circuits. This also provides for adjusting the machine for different frequencies, if desired. The stator is energized with direct current, which induces an alternating current into the rotor, as in any generator. This is usually arranged for a frequency of 15,000 cycles per second, and the rotor resonance circuit is tuned for exactly that frequency. As this produces a magnetic field which *reverses* its direction 30,000 times per second, a corresponding E. M. F. is set up in the stator, by having that circuit tuned for resonance with a frequency of 30,000. This 30,000-cycle current then induces into the rotor a frequency of 45,000 cycles, which in turn reinduces a 60,000-cycle current into the stator. The antenna circuit is carefully tuned for resonance with a 60,000-cycle frequency, and waves of this frequency are radiated from the antenna. By making use of this reflection principle, it is possible to obtain high-frequency current without the construction of a generator of the practically impossible size and number of field poles that would be required in the ordinary type of alternator. A 200-K. W. Alternator of this type was in use for several years at Station WCI, Tuckerton, New Jersey.

280. A novel transmitter combining some principles used in both the Goldschmidt and Alexanderson alternator has been developed in Germany. A description of this appears in the *Radio News* of January, 1923, from which the following extracts are taken: "While in the Goldschmidt machine used in Nauen, a repeated changing of the fundamental frequency of the high-frequency current used for sending is obtained, *Schmidt* has succeeded with a single transformer, in one step, and without direct-current magnetizations, in reaching this frequency. An alternating-current machine of average frequency of, say, 6,000 cycles works in series with a condenser, on the winding of the frequency trans-

former. C_1 is of such a capacity that the circuits of the machine are in resonance with the fundamental frequency impressed by the alternating-current machine. The high-frequency circuit is connected directly to this winding, that is, between the points a and b. According to the choice of tuning in the secondary circuit, currents of a multiple of the frequency of the machine are directly obtained. The two high-frequency windings, ww, are so connected that the magnetic field that is developed in the direct-current winding, wg, is in opposition, and no high-frequency potential is induced in wg, whereas the force developed in wg passes through the high-frequency windings. The antenna is in tune with the sending waves, while the key is pressed. By releasing the key, in consequence of the great self-induction, not only a detuning but also the resistance of the high-frequency coil increases so that the antenna current falls to zero. The field and the armature windings are placed on the

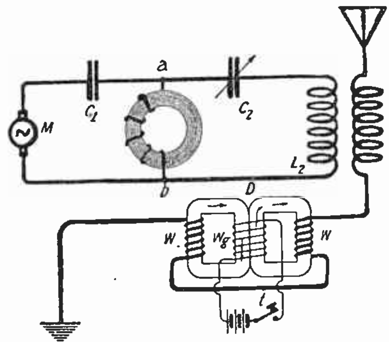


Fig. 218. Diagram of Schmidt High-Frequency Alternator.

stationary portion of the machine, as in the Alexanderson alternator. The rotating portion consists of a cast-steel body with no winding, fitted with teeth, whose interspaces are not filled with unmagnetic metal, as in the Alexanderson machine. If the apparatus is to be used for wireless telephony, one has only to replace the key by a microphone."

281. The *Joly-Arco* continuous-wave transmitter, of the Telefunken Company, consists of an alternator of a frequency of from 10,000 to 15,000 cycles, with two magnetically saturated closed-core transformers connected with

their secondaries in circuit with the antenna, and with a battery supplying additional current to a third winding which is placed on the iron-core transformers between the primary and secondary windings. The effect of these windings is to *double the frequency.* When the current through the primary of the transformer 1 is in such a direction that the magnetic flux of that solenoid is in the same direction as that of the core, this has no effect upon the magnetism of that core, because it is already saturated; but at the same time, the magnetism of the primary solenoid of transformer 2 will oppose the magnetism of that core and reduce it, on account of the two primary solenoids being wound in opposite directions, one clockwise and the other counterclockwise. When the alternation in the *opposite direction* traverses the primary circuit, the same thing will take place with the relation of the transformers reversed. The result of this is to make two changes in the magnetic flux of the transformer cores alternately; and with the antenna circuit tuned to resonance with the doubled frequency, a current of twice the

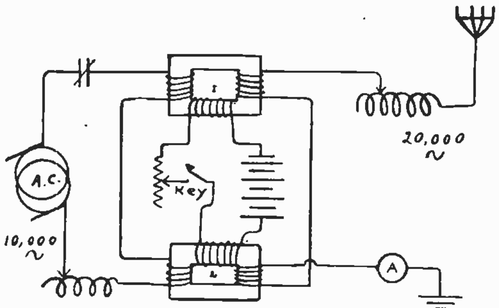


Fig. 219a. Diagram of Joly-Arco Transmitter.

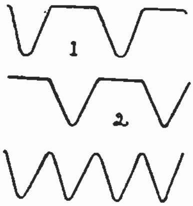


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Fig. 219b. Curves Showing Development of Double Frequency.

alternator frequency will flow in the antenna. These are sometimes referred to as frequency doubling transformers, or static frequency transformers.

A 100-K. W. transmitter of this type has been in use for several years in the Naval Radio Station at Sayville, Long Island. It employs two doublers. The original frequency of the a. c. generator is 9,613 cycles. This is doubled to 19,226, and again to 38,452, giving an output of about 7,800 meters. The wave length radiated can be varied by changing the speed of the alternator. The keying arrangement used is similar to the magnetic modulator used with the Alexanderson alternator.

If the intermediate battery circuit is omitted the frequency of the alternator is *tripled.* However, this has not proved as practical in actual use as the doubler.

282. The *Marconi timed-spark* system of transmitting continuous waves consists of a number of synchronous rotary gaps mounted on a common shaft and so arranged that their successive sparks, occurring at different instants, combine to produce one continuous set of oscillations. A modified form of this timed-spark apparatus is shown in figure 220. One 10,000-volt d. c. generator is used, in series with a large choke coil. The two condensers shunted across the generator receive the initial charge from the generator; and this charge simultaneously discharges across the spark gaps, as they come in proper relation for this to take place, and

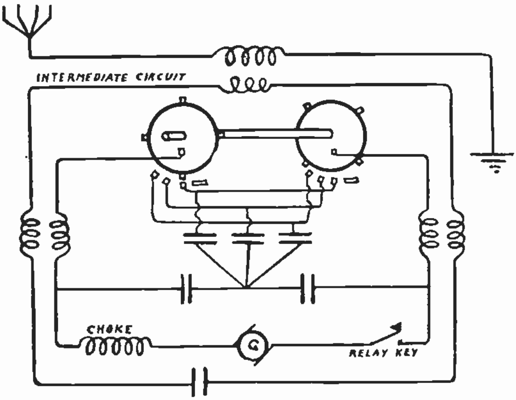


Fig. 220. Marconi Timed-Spark Transmitter, Modified Form. (Bucher.)

charges the three condensers in the center, through first one inductance coil and then the other. These three condensers are consecutively discharged. These various sets of oscillatory discharges are inductively conveyed to an intermediate circuit, where they unite in a manner which induces continuous waves to be radiated from the antenna.

283. The *arc converter* is an adaptation of the well-known principle that when two electrodes are struck together and then drawn apart, the current will continue to pass between

them after they have been separated a small distance, forming an electric arc, the name of arc having been given to it on account of its tendency to bend, or take the form of an arc. An arc gives off light and heat, and when under control may be very useful, but when not under control, as in case of an accidental arc between broken ends of a charged cable, may do vast damage. The *Fire Underwriters' Requirements,* by Dana Pierce, gives the following description of an electric arc: "An arc is the visible evidence that the current is passing from one conductor to another, or across a break or gap through the air or over an insulating surface. An arc always causes heat and, if any appreciable current passes, the arc will be very hot and if continued is capable of melting the adjacent metal at the gap or setting fire to any combustible nearby." When two carbon electrodes are connected to opposite sides of a source of supply, first touched, and then separated a fraction of an inch, the current passes across the space between the electrodes, and we have an *arc lamp.* The tips of the carbon electrodes become *incandescent,* giving off a brilliant light, and they are gradually consumed. As this consumption takes place, the carbon is vaporized, this carbon vapor being a better conductor of electricity than the air and maintaining the current across the arc. The positive electrode is consumed much more rapidly than the one on the negative side of the current. In practice the arc lamp is kept in operation by an automatic electromagnetically-operated device which keeps the two electrodes in proper relation. This varies in different makes and types of lamps. The rapidly burning positive electrode is placed vertically above the negative. Usually there are two electromagnets, one in series with the positive electrode and the other in shunt to the arc. When the lamp is not in use the electrodes touch. When the main switch is closed the current operates the solenoids, which have opposite polarities, in the following manner. The solenoid in series with the upper electrode raises that electrode away from the negative, thus automatically "striking the arc." As the electrodes are consumed, increasing the distance between them, which increases the resistance, more current flows through the shunt solenoid. When this current through the shunt coil reaches a certain value it operates an armature which releases the clutch in which the positive electrode is held, thus forming an automatic feed. It has been found

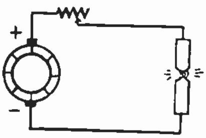


Fig. 221. Simple Arc Lamp.

that when the electrodes of an arc lamp are enclosed in a glass case which is nearly air-tight, the life of the electrodes is extended to fifteen or twenty times their life in the open air. This is on account of excluding the oxygen. Arc lamps will operate on either direct or alternating current. When alternating current is used, the decomposition of the two carbon electrodes is equal, because the polarity is alternately reversed between them.

284. In about 1900 Duddell discovered that if a condenser and a coil of wire, of the right capacity and inductance, were shunted around a direct-current arc, the arc would produce a musical note. From this it was first called the "singing arc." *The principle of action is as follows:* When the condenser and inductance coil are shunted around the arc, the direct current flowing across the arc is *drawn away* from the arc to charge the condenser. Because the current from the d. c. generator can not be suddenly increased, charging the condenser *robs the arc of current.* As the current across the arc is decreased, the space between the electrodes is cooled, the number of heated ions is reduced, and the *difference in potential* between the arc electrodes *rises.*

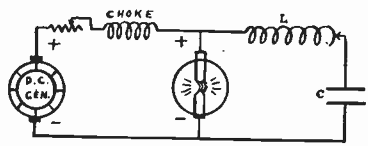


Fig. 222. The Singing Arc.

Tracing the movement of electrons from negative to positive, one can imagine them first rushing across the arc gap, as the electrodes are struck and then separated. Then *the condenser capacity attracting them,* the upper plate of the condenser becomes positive, and a negative charge accumulates on the lower condenser plate. For a fraction of a second there is no current passing between the arc electrodes. They begin to cool, and their difference of potential rises. Then, as the upper condenser plate becomes more positive, there is an instant at which the positive voltage of the generator is neutralized by the positive back pressure of the upper condenser plate and, the condenser being charged to its full capacity, no more negative electrons are added to the lower condenser plate. Then this condition of strain breaks down. *The positive attraction of the upper half of the circuit draws a rush of electrons from the negative side, consisting of the combined electron charge drawn away from the lower plate of the condenser and the negative electrons from the generator.* The arc current at this instant is *twice* the generator current. As the positive attraction of the upper plate of the condenser is stronger than that of the generator, most of this current passes through the inductance coil L, forming a magnetic field which collapses and *charges the condenser with a polarity opposite to its first charge.* The upper plate of the condenser is now negative, and the bottom one positive. For another instant the condition of strain exists. The negative polarity of the upper condenser plate opposes the negative polarity of the lower arc electrode. The arc current is zero and its voltage rises. Then this second condenser charge is released through the inductance coil L, and is *drawn back to the positive pole of the generator,* the positive attraction of the lower condenser plate at the same instant starting to draw another negative charge from the negative pole of the generator. *While current passes in both directions through the coil L, and the condenser charges alternately in each direction, the current across the arc is a one-way pulsating current.* A peculiarity of the arc is that it appears to operate opposite to Ohm's law, that is, the current across the arc is not greatest when the arc voltage is greatest, but exactly opposite. This is accounted for by the resistance variation of the space between the arc electrodes, as the latter heat and cool. It is this *negative resistance,* or falling potential characteristic, that makes it possible to generate high-frequency oscillations with the arc.

285. Many types of radio-telegraph transmitters making use of the arc for generating continuous oscillations have been devised. The best known one which has reached a standardized stage of practical usefulness is the one worked out in 1913 by Professor Valdimar Poulsen of Denmark, and developed and improved by the Federal Telegraph Company of San Francisco. This is used extensively in the U. S. Navy, both on sea and land, to a small extent in the Merchant Marine, and is installed throughout the country in various post office radio stations, where it is used for communication connected with the aerial mail.

286. Having proved in many ways that the capacity between an antenna and the ground is the equivalent of a condenser, it can be seen how we can substitute the antenna and ground capacity for the condenser, and have the singing arc perform in exactly the same manner that it does with the "dummy antenna." In this case, *generator current is delivered directly* into the antenna for every other alternation.

In figure 223 the fundamental principles of an arc transmitter are indicated. This transmitter is usually called an *arc converter,* because it converts direct current into high-frequency alternating current. It will be noticed that two electromagnets have been added, with their windings connected in series with the supply line. These are called "blow out" magnets, their function being to blow out the arc between oscillations, or to hasten the change from minimum pressure to maximum pressure by deionizing the space between the electrodes with a powerful magnetic field which literally sweeps the heated ions out of the way. This causes the arc to operate with greater snap. The magnet windings being in series with the line secures a double use of them.

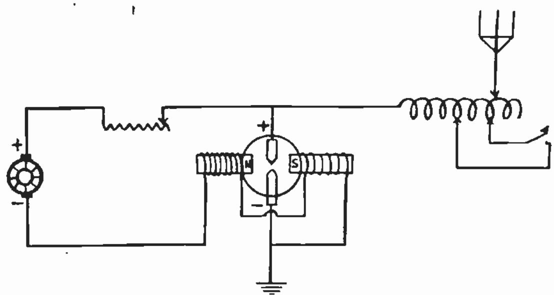


Fig. 223. Fundamental Arc Transmitter.

They also serve as choke coils, protecting the generator from possible "back kicks" from the high-frequency circuit, and keeping the generator current supplied to the arc steadily. The *period* of oscillation of the arc high-frequency circuit, and hence of the radiated wave, depends solely upon the inductance and capacity of the circuit. This may be controlled by variation of inductance only, or an additional short-wave condenser may be used. The positive and negative electrodes are sometimes called respectively the *anode* and *cathode* of the arc.

287. When used for radio transmitters, the arc electrodes consist of a carbon negative and a copper positive enclosed in a non-magnetic phosphor bronze chamber. Frequently the positive is made of brass with a copper tip, which is renewable. The carbon positive is not necessary for the production of oscillating current; and it is this, and not light, which is sought. This confines the rapid decomposition to the negative carbon electrode. The carbon is slowly rotated by a motor, causing the arc to burn more evenly and the electrode to retain a symmetrical point. Both electrodes are insulated from the chamber. The positive electrode contains a bore through which water is circulated to keep it from melting from the intense heat of the arc. The chamber is double, and water circulates in the space between the outer and inner sections. Systems of cooling the water vary somewhat. The usual method in low and medium-powered stations is known as the thermo-syphon circulating system. In this a large elevated water tank is connected in such a manner that the heated water automatically rises to the top of the tank and the cooled water returns to the chamber. (See figure 225.) The cool water inlet is at the upper side of the positive electrode. The water then flows through this electrode, to the bottom of the chamber, through the water cooled sheath in which the negative carbon holder turns, and to the top of the water tank. The water is kept in circulation by means of a centrifugal pump located on the end of the shaft of the carbon rotating motor. In some of the largest high-powered land stations, the water is supplied directly from the hydrant water supply through rubber hose, which provides cooler water than the syphon system. Care is required in this method, in order to avoid grounding the arc. At Annapolis the water used for cooling the arc is emptied into an outdoor pool, pumped through a fountain, and returned to the arc. Much greater radiation is secured from the arc on a given voltage if it is allowed to burn in an atmosphere of hydrogen. This is obtained in various ways. A liquid hydrocarbon such as kerosene may be dropped into the space between the arc electrodes, where it is immediately decomposed by the heat, releasing hydrogen. Or alcohol may be vaporized by dropping it into the arc. This is preferable, as the burning kerosene forms a black soot within the arc chamber, which is very annoying and has to be continually

cleaned out. The liquid used for this purpose is conveyed to the arc by means of a small tube leading from a glass container placed directly over the chamber. The reason for the increased radiation when the arc burns in an atmosphere of hydrogen, is that this produces a purer wave. It has been proved by experiment that the oscillations in the radiated signals would have different amplitudes, approaching somewhat the characteristics of the damped waves of a spark transmitter, unless strong blowout magnets and hydrogen are used. These produce the most even operation of the arc, and provide smooth continuous waves to be radiated.

288. As the arc is oscillating continuously while the set is in operation, the methods of signaling must necessarily be different from those used with the spark transmitter. The key must be connected in some manner in the antenna circuit, as the arc will not operate if the direct current from the generator to the arc be interrupted. The simplest way of making signals, now becoming obsolete, is to connect the key to the inductance coil in the antenna circuit, as shown in figure 223. With this method, each time that the key is pressed the inductance is changed, with a consequent change in the wave length of the radiated wave. The arc is operating continually, and radiation is going on continuously; but as pressing the key causes radiation on a wave length other than the non-signaling wave length, the signals are readable when tuned in by a receiving station. The open-circuit wave length is called the compensating wave, and the one which is radiated by pressing the key the operating wave. For instance, if the natural wave length of the antenna is 4,550 meters, and the operating wave caused by changing the antenna inductance 4,500 meters, a receiver properly tuned to receive 4,500 meters, will respond to that wave length only, and the operator will hear only the dots and dashes formed on the operating wave of the transmitter. If the receiving apparatus is not properly tuned he may hear both waves, or possibly the compensating wave only. This compensating wave also interferes with other receiving stations. The arc transmitter also frequently radiates *"harmonics,"* or additional vibrations of a much higher frequency than the main wave frequency, and a multiple thereof. Sometimes in addition to harmonics there are still other groups of waves of an intermediate frequency, generally referred to among practical operators as "mush." These extra vibrations are objectionable, due to their interference.

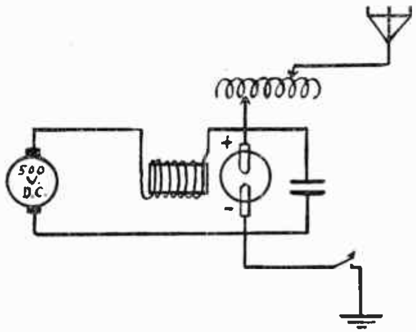


Fig. 224. Antenna-Ground Signaling System.

289. Several signaling methods are in use, the object of each being to prevent the radiation of the compensating wave. Perhaps the simplest non-compensating wave method of arc signaling is shown in figure 224. With high-powered sets the antenna ground circuit is closed and opened by a magnetic relay operated by a Morse hand key. Or several relays may be connected in parallel for this purpose, to take care of the large amount of current. In low-powered arc sets, where the current is small enough to permit, a key is connected directly in the antenna ground circuit. This is a special type of key having renewable silver electrodes. When the key is pressed, the oscillations flow in the antenna and electric waves are radiated. The shunted condenser is then acting as a "booster" condenser. When the key is open the arc continues to oscillate within the closed condenser circuit, but nothing is radiated, because there is no ground connection. This signaling system has been used for several years in some of the installations of the U. S. Navy. In the arc transmitter illustrated in figure 225, the circuit to the carbon-rotating motor is arranged with contact points which may be opened or closed by a brass button on the transmitting blade of the antenna change-over switch. When the antenna switch is thrown to send position, this button closes the motor circuit and starts this part of the device into operation. The motor starts up, turning the carbon, and the centrifugal pump on the end of the shaft of this motor sets the water into circulation. The arc may then be started to oscillating by "striking" the electrodes. When the antenna switch is thrown to the receive position, the button breaks contact with the carbon motor circuit, leaving this open. The carbon then ceases to revolve, the water stops circulat-

ing, and the carbon is automatically drawn far enough out to cause the arc to stop. When it is desired to send again, and the change-over switch is thrown to send position, starting the motor and the water circulation, all that is necessary is to strike the arc again, when transmission may be resumed.

In high-powered stations using this method of keying there are usually a number of relays connected in parallel to reduce sparking, and they may be connected on the induct-

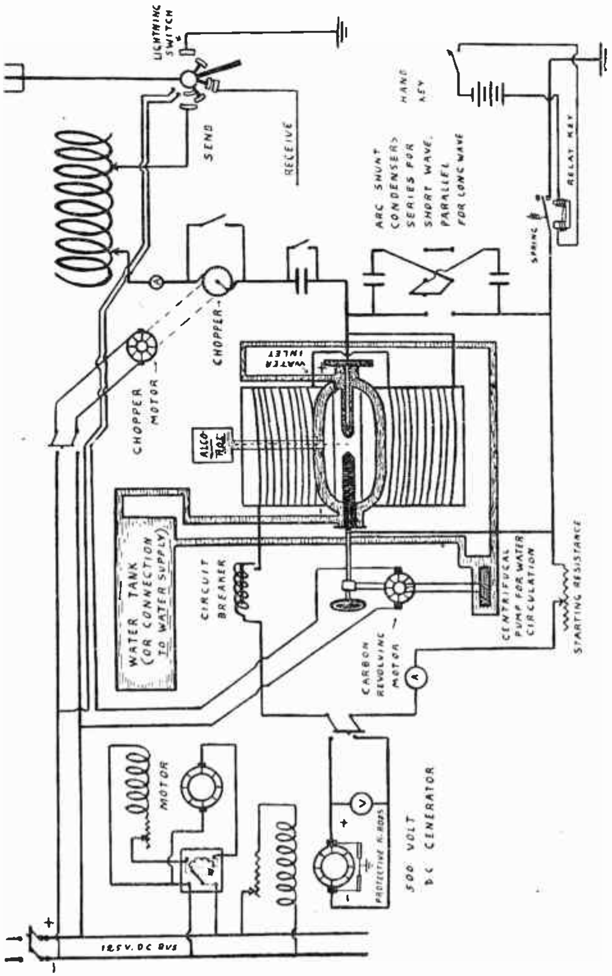


Fig. 225. 5-K. W. Arc Transmitter, as used in the U. S. Navy. This shows the Water-Cooling System and Automatic Carbon Motor Control.

ance coil side of the antenna system instead of in the ground lead.

290. The method of signaling which is generally considered most successful, especially for low and medium-powered sets, is known as the back-shunt system. In this the arc is shunted by a "dummy antenna" containing inductance, capacity and resistance. When the arc main-line switch is closed, and the arc is struck, the arc oscillates in the back-shunt circuit. When the key is pressed, supplying the solenoid of the relay key with current, as indicated

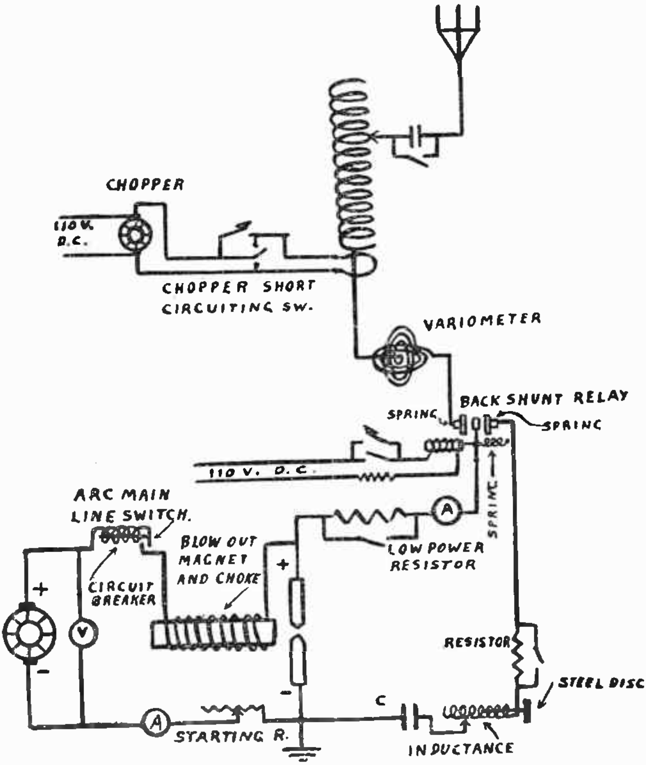


Fig. 226. Federal Telegraph Company's Arc Transmitter with Back-Shunt Signaling System.

(The blowout magnet winding may be in two sections, arranged to present a north and south pole to the arc gap, or, in the high-powered apparatus, it may be a single winding having a "yoke" core, which provides the opposite polarities.)

in figure 226, the plunger is drawn into the solenoid, and the relay key makes contact with the antenna circuit. This disconnects the arc from the back-shunt circuit. When the signaling key is released the relay key flies back, and the antenna is disconnected from the arc, and radiation ceases, although the arc continues to oscillate. The relay contacts are controlled by springs, preventing a break in the circuit until the change from one to the other has been made. The relay key, when properly adjusted, has a motion of about one thirty-second of an inch. The resistance in the back-shunt circuit is varied so that the current in that circuit and the antenna will be of the same value. A fixed resistance, shunted by a switch, is mounted at the top of the back-shunt unit. The current in the circuit is then regulated by means of a circular steel disc placed at the end of the inductance coil. This disc is revolved on a threaded shaft by means of a small handle. When it is near the coil, the high-frequency magnetic field of the coil produces hysteresis losses due to eddy currents set up in the disc, and the effect is that of adding resistance to the circuit. When the plate is moved away from the coil the effective resistance is reduced and more current flows in the circuit. Successful operation of the back-shunt signaling system requires accurate adjustment of this disc. If it is too badly out of adjustment the arc may cease to oscillate. The direct-current input must be the same whether the arc is connected to the antenna or to the back-shunt circuit. With back-shunt systems of 5-K. W. or more, the power-balancing resistor contains a series of taps, with a permanent connection for each wave-length. If properly installed, the correct power balance will always be automatically secured for each wave length. A variometer in the antenna circuit is used for varying the wave length, within limitations. Low-Power Resistance units, with cutout switches, are also provided in the antenna and the back-shunt circuit.

Fig. 227 Edge of Chopper Disc.

Arc stations are generally equipped with a chopper to use when it is desired to communicate with receiving stations not prepared for receiving uninterrupted continuous waves. The chopper, consisting of a small motor-driven disc having many segments insulated from each other, is revolved under slipping-contact brushes, thus breaking the continuous waves into groups of waves of audible frequency. In figure 225 the chopper is shown connected in series with the antenna, and in figure 226 it is inductively coupled to the antenna by a single turn of wire. This loop detunes the antenna and varies the wave length, so that signaling is done with a compensating wave when the key in this circuit is used. However, by short-circuiting this key, and inductively coup-

Fig. 228. Chopper-Interrupted Continuous Waves.

ling the chopper to the antenna, the audible-frequency changes made in the radiated waves will make the signals audible on a crystal-detector receiving set when the arc signaling is acomplished with the back-shunt circuit, which radiates no compensating wave. The plain absorption-loop method of signaling could also be used, if desired in case of emergency, by not starting the chopper motor, and throwing the switch under the chopper key to the lower contact. This would radiate a compensating wave.

291. Another method of eliminating the compensating wave is called the *ignition* system. This consists of an arrangement amounting to another small arc enclosed within the arc chamber, and operated by the key in conjunction with an electromagnetic relay. This is the ignition key, and its function is to ignite and extinguish the arc flame for signaling purposes after the arc has once been started by the usual striking process. The ignition key will not operate when the arc is cold. When the signaling key is raised, the striking rod of the ignition key makes contact with the stationary electrode, and the arc is short-circuited by the ignition key and the absorbing resistor, so that the arc is extinguished. If, while the arc electrodes are still hot, the key is closed, causing the striking contact of the ignition key to separate from the stationary part, the current will arc across the ignition electrodes; and the strong magnetic field of the blowout magnets blows this flame between the electrodes of the main arc, and the latter is reignited and again oscillates. So, for each dot and dash of the signaling code, the arc is ignited by the small arc produced by the ignition key, and for each space between the dots and dashes the arc is extinguished. As soon as the main arc is reignited, the arc across the ignition key electrodes ceases, as there is no current in that part of the circuit then.

292. The lowest powered arc transmitter made by the Federal Telegraph Co. is the 2 K. W. This is usually supplied with current from a 500-volt d. c. generator; and when properly installed by the Federal Telegraph Company's engineers always has all of the switches, coils, etc., arranged so that they present about the same general appearance. An *exhaust valve* is provided, which allows the escape of

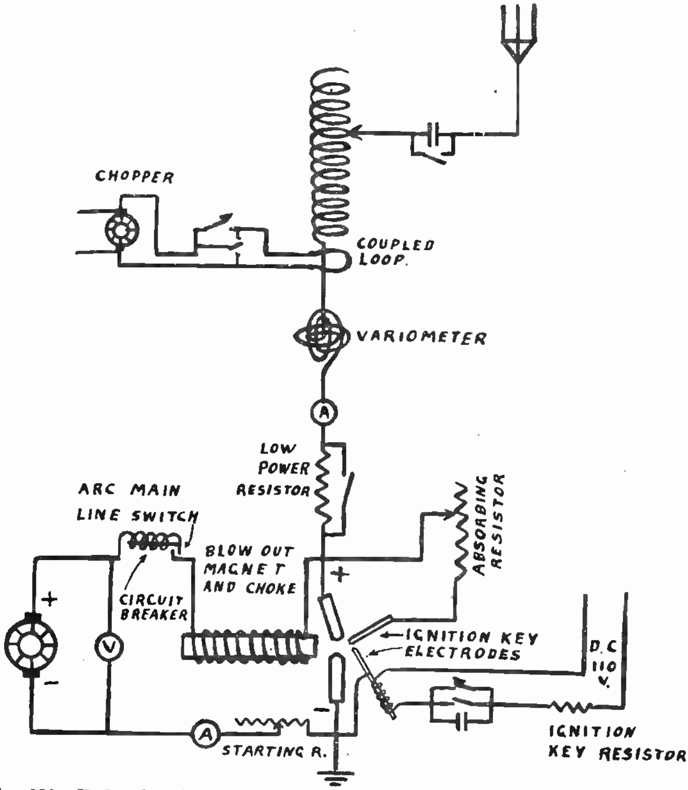


Fig. 229. Federal Telegraph Company's Arc Transmitter with Ignition Key.

the carbonized hydrogen gas in case of too much alcohol being admitted to the arc chamber. This also serves as a safety outlet in case of an explosion, and assists in reducing the heat within the chamber. In the 2-K. W. set, this exhaust is connected with a pressure regulator, which is simply an aluminum case containing a rubber partition

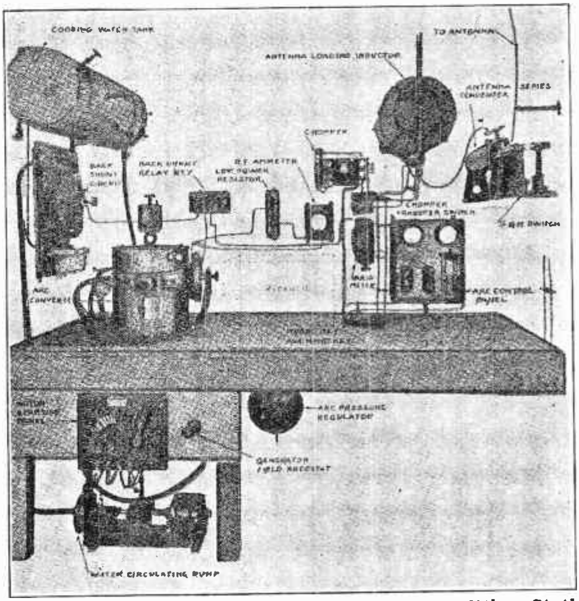


Fig. 230. Federal Telegraph 2-K. W. Arc Transmitting Station.

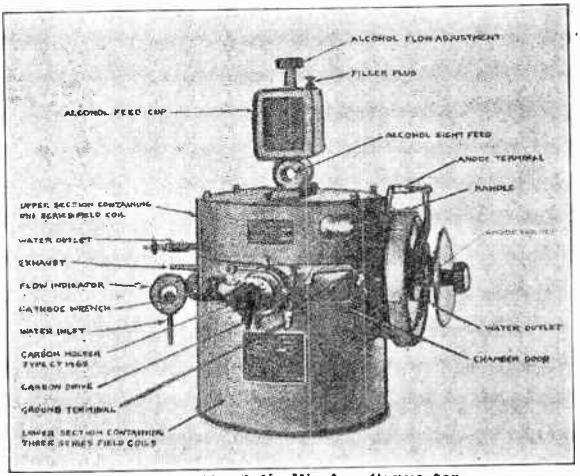


Fig. 231. 2-K. W. Arc Converter.

against which the exhaust discharge is directed. In some of the large stations the arc chamber is filled with illuminating gas, which contains considerable hydrogen, instead of obtaining hydrogen by the previously described drip method. The *magnets* in the high-powered arc transmitters also have special cooling arrangements. This may consist of bores through the iron cores, with oil pumped through these, or the windings may be immersed in oil. The latter

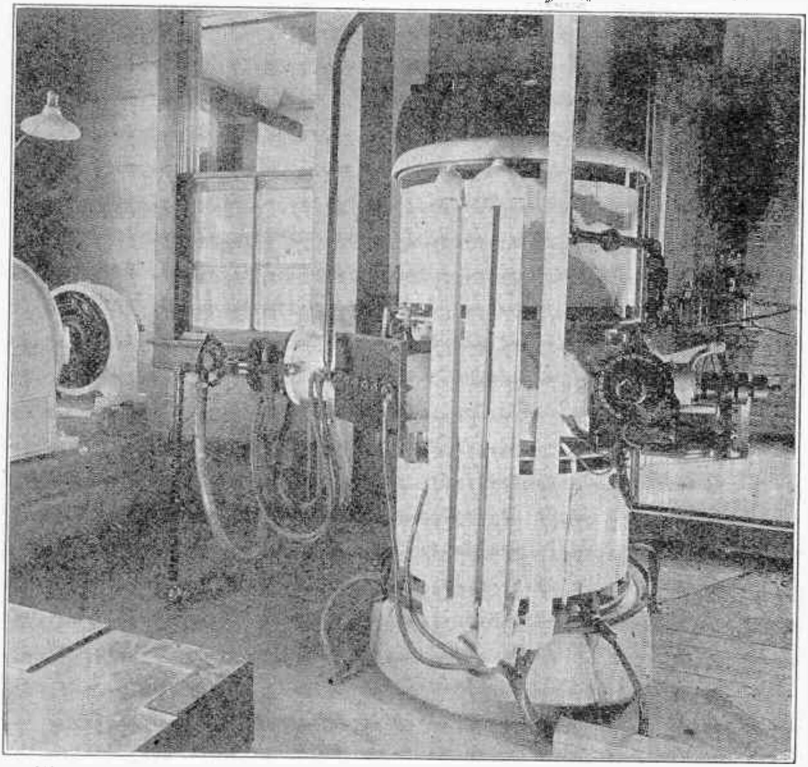


Fig. 232. 30-K. W. Arc Converter at WVB, "Army Net" Station of the U. S. Signal Corps, Fort Sam Houston, Texas, March, 1926. (See appendix for map of Army Radio Net.)

method is used in the high-powered arc installation of the U. S. Navy at Annapolis. Two 500-kilowatt converters, of the type illustrated in figure 235, are installed as duplicates. The yoke-type of magnet core is employed, the field winding being placed around the lower pole, and the magnetic circuit closed through the bedplate and yoke. The tank in figure 235, just below the arc chamber, contains the coil, *immersed in oil* for insulating and cooling purposes.

The coil is made in 15 sections, composed of flat windings of copper strip. Six of these windings serve as a choke. The remainder are provided with variable connections by means of which one or more of them can be short circuited. *For relatively short wave lengths, a strong magnetic field is required, while a weaker magnetic field gives better results on longer wave lengths.* Leads from these sections of the

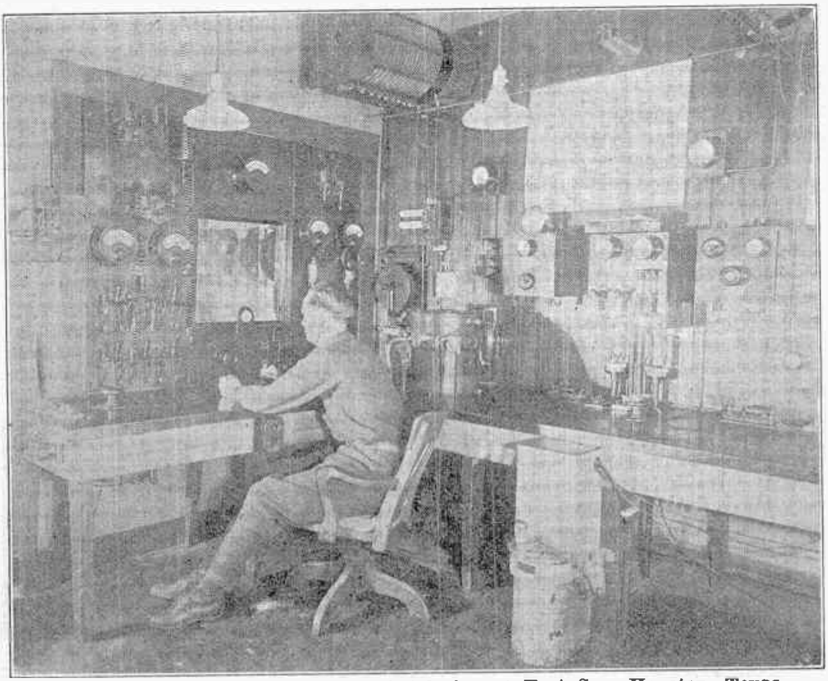


Fig. 233. Control Panels for 30-K. W. Arc at Fort Sam Houston, Texas. WVB.

(At the right is shown a complete 5-K. W. model A. D. arc installation. The motor-generator for the 30-K. W. arc. which the operator can see through the window, is controlled by a stop-start push-button immediately in front of him. The motor-generator for the 5-K. W. arc is behind the operator's chair.)

magnet winding are attached to connections on the wave-length-changing switch, so that they are automatically taken care of in tuning the apparatus. The oil tank is equipped with a non-magnetic brass cover, and a motor-driven pump circulates the oil through water-cooled coils located in a concrete pit outside of the building.

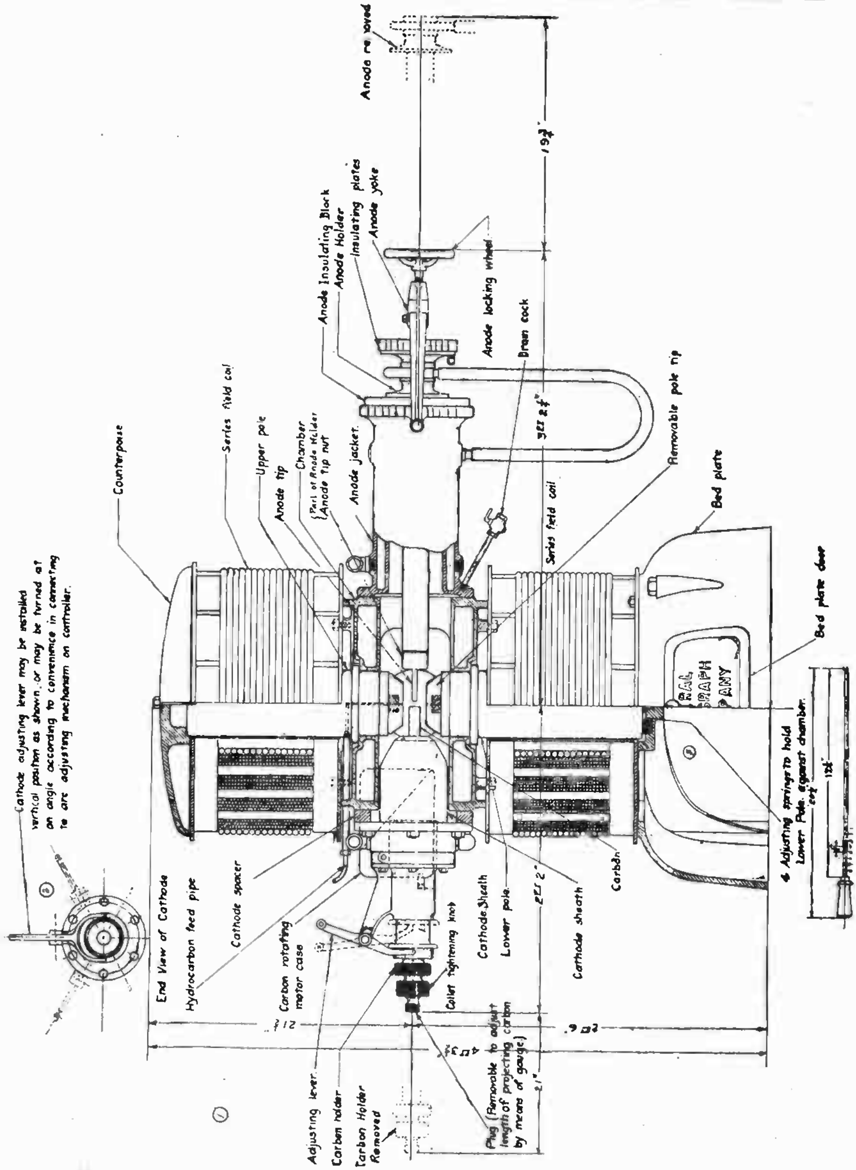


Fig. 234. **Details of Construction of Federal Telegraph Company's 30-K. W. Arc Converter.**
(Robinson's *Manual of Radio Telegraphy and Telephony.*)

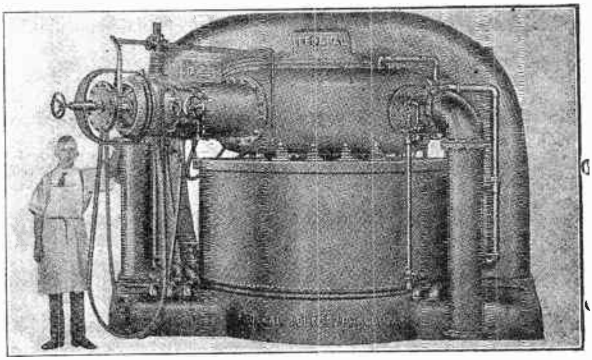


Fig. 235. 1000-K. W. Arc Converter of the Federal Telegraph Co.

In this country the arc transmitter is usually conductively coupled to the antenna. In Europe the inductive coupling is more frequently used with the arc. The Federal Telegraph Company's list of stations includes the following: San Diego, Guam, Pearl Harbor, Cavite, Java, Vladivostock, Mare Island, San Juan, Darien, Fort Bliss, Boston, Say-

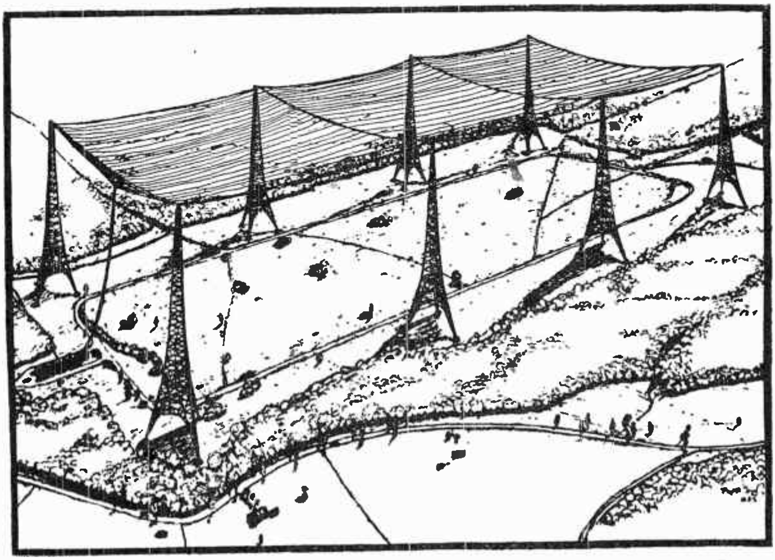


Fig. 236. Towers of LY, 1000-K. W. Arc Station at Lafayette, Near Bordeaux, France, Wave Length, 19,100 Meters, Range 12,000 Miles.

ville, Norfolk, Key West, Fort Sam Houston, and the Lafayette station near Bordeaux, France, where a 1,000-K. W. arc converter was installed by American engineers during the World War.

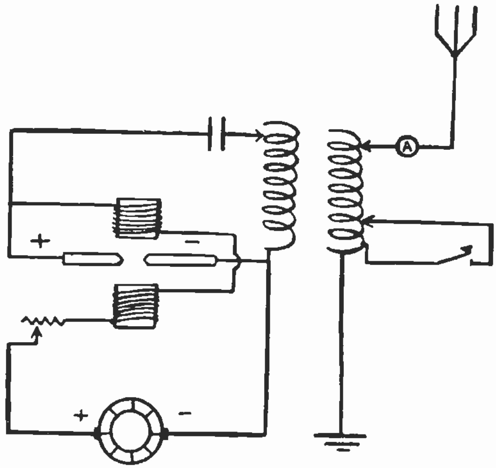


Fig. 237. Inductively Coupled Arc Transmitter.

293. The antenna ammeter is connected in series between the arc electrodes and the antenna. This is seldom connected in the ground lead. When starting the arc, the ammeter indicates that the arc is oscillating, as otherwise there would be no current in the high-frequency circuit. When the apparatus is correctly adjusted, the antenna ammeter reading will be approximately .707 of the direct current of the charging source, or the effective value of the alternating current will be as explained in paragraph 96. *With the generator field rheostat adjusted, it is possible to vary the arc voltage by varying the length of the arc gap.* As a great deal of heat is generated in the arc chamber, the *total power* of the high-frequency circuit is rarely more than 50 per cent. of the applied d. c. power.

Directions for starting the arc transmitter into operation, based on instructions given out by the Federal Telegraph Company, are as follows:

Precautions to be observed before starting arc:

1. Make certain that the water tank is at least three-fourths full of fresh water.

2. Be sure that all valves of the water circulating system are open.

3. Start the water pump and make sure that water is circulating through all water-cooled parts of the arc converter unit.

4. Be sure that all moving parts are properly lubricated.

5. Make sure that there is a supply of alcohol in the alcohol container and that it feeds properly.

To start the arc:

1. Close the short-circuiting switch on the Morse hand key. If using the ignition key signaling system this opens the contacts of the ignition key, permitting the arc flame to function. In case of the back-shunt system, closing the switch around the Morse hand key will connect the arc converter to the antenna.

2. Close the main-line supply switch.

3. Throw the antenna change-over switch to send position. This automatically starts the water into circulation. Make sure that the water is circulating properly.

4. Start the motor-generator by closing the circuit-breaker on the motor starting panel and then increase the speed of the motor by gradually moving the handle of the starting box to the "on" position.

5. Adjust the voltage of the generator, observing volt meter reading.

6. Start the flow of alcohol, permitting it to drop rapidly.

7. Adjust the carbon electrode to a distance of about one thirty-second of an inch from the copper electrode.

8. Adjust arc starting resistance to maximum position, and close the arc main-line switch.

9. Strike the arc by pushing inward on the adjustment knob. This should be done with a quick, snappy movement, without too much force, so as to allow the controlling spring to throw the carbon back to its original position, otherwise the arc will short circuit, causing the circuit-breaker to fly open, and the apparatus to come to a standstill. The knack of striking the arc requires a little practice. It may be necessary to strike the carbon holder several times before the arc flame is started. As soon as the arc flame is started the electrodes should be adjusted until oscillations are produced. When this is accomplished the arc starting resistance may be cut out of the circuit.

10. Signals may now be sent, after opening the switch around the Morse hand key.

CHAPTER 32

The Principle of the Vacuum Tube

Historical Development of Vacuum Tube — Edison Effect — Fleming Valve — Electron Theory of Vacuum Tubes—Characteristic Curves of Vacuum Tubes—Eaton Collection of All Types of Tubes from Earliest Down to Present

294. With the development of the *vacuum tube,* a new era was opened in radio. This development is still in progress, and indications are that much greater things may be expected of it in the future. While the "spark set" will no doubt continue in use for some time in old installations on ships, it appears to be the general opinion that it will eventually be replaced by continuous-wave apparatus of some type, possibly by vacuum-tube apparatus exclusively. The uses of the tube are many. It may be employed for a simple detector of damped waves, as a detector for undamped waves, for amplifying the volume of received signals, and for generating oscillations for the transmission of telegraphic signals or speech. Tubes are manufactured in many types and sizes to meet these different requirements, ranging from tiny glass tubes about two inches long and as large around as a lead pencil to metal tanks resembling hot water boilers. One of the many advantages of vacuum-tube apparatus is its compactness. With the introduction of tubes, the bulk of radio apparatus was greatly reduced; and during the World War communication was carried on between aeroplanes, tanks, submarines, etc., by means of small portable vacuum-tube devices which would have been declared impossible a very few years before.

295. The vacuum tube is an adaptation of the *incandescent lamp* which was invented by Thomas Edison in about 1883. It is based on the principle of utilizing the emission of electrons from a heated wire. A filament of carbon or tungsten wire is enclosed in a glass tube or globe, which excludes the air. When an electric current is passed through the filament, the resistance of the metal causes the wire to become incandescent. The space within the tube, when it is used for a light, may be filled with nitrogen or some other

form of gas, or it may be exhausted so as to form a vacuum. In about 1884 Edison discovered that if a second element, such as a second wire, be placed within an electric light globe, and the filament heated to incandescence, current would flow between the second element and the filament when the second element was given a positive potential, and that the current through the space within the tube ceased when the filament current was cut off, and varied in proportion to variations made in the resistance inserted in series with the filament source of supply. This is now generally known as the *"Edison effect."* Edison, although discovering this phenomenon, found no practical use for it, and it re-

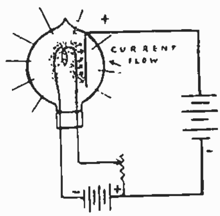


Fig. 238. Illustration of the Edison Effect in an Electric Light Globe.

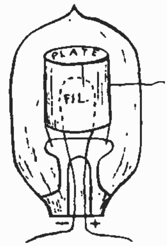


Fig. 239. Fleming Valve.

mained for Dr. J. A. Fleming, of London, in 1904, to discover its rectifying characteristics and its adaptability to the reception of radio telegraph signals. For this reason the first vacuum-tube detectors were called Fleming valves. The second element is now generally called the *plate,* and the current between the plate and the filament is known as *plate current.* Modern vacuum tubes contain a third element, known as the *grid.* This was added by Dr. Lee De Forest in 1909.

296. Taking up the operation of the vacuum tube more in detail, it is necessary to understand the *electron theory.* It is a well known fact that when any piece of metal or wire is heated to a white heat, it will throw off ultramicroscopic particles. These are called electrons. They carry a negative electric charge, while the heated body maintains a positive charge, caused by the lack of negative electrons. The negative electrons thrown off are immediately attracted back by the positive charge, and immediately dance off into space again. These movements take place at terrific speed and the number of electrons must be innumerable millions. Dr.

Robert Millikan, who received the $40,000 Noble Prize for the Advancement of Science, in recognition of his important research work in connection with *electrons*, refers to them as *actual matter*, and *"granular."* When the heated element is a filament enclosed in an air tight globe, the space surrounding the incandescent filament is charged with negative electricity as long as the filament remains heated; and the greater the heat of the filament, the stronger will be the negative space charge within the bulb. Now, if a second element, or electrode, be inserted into this negatively charged space, and at the same time connected in series with the filament circuit, and given a positive charge from a battery, that which we generally speak of as a "current flow" will take place. *The negative electrons which are thrown off from the filament are not attracted back to their source, as when there was no second element within the space, but are drawn to the plate, on account of its positive charge being stronger than the positive charge of the heated filament.* If the polarity of the plate battery is reversed, there will be no flow of current through the tube. The negative charge on the plate will repel the negative electrons, and no current can flow in either direction. An increase of filament voltage, which increases the emission of negative electrons, will increase the flow of plate current, until a point of *saturation* is reached. At this point the temperature of the filament is such that no more electrons can be thrown off per second, and the space within the tube has reached a state of charge which neutralizes any increased attraction for the electrons. Beyond this saturation point an increase of the filament voltage, or current, has no effect, except to destroy the filament. With any fixed charge of the filament, an increase in the voltage on the plate will also increase the flow of plate current, up to the point of saturation, beyond which no increased plate current can be obtained with increased plate voltage. In figure 238 the *current* is indicated as flowing *from the filament to the plate,* which is in accordance with our present understanding of an electric current as consisting of a movement of negative electrons from the negative toward the positive through a circuit—and contrary to the traditional theory which stated that the direction of current through a vacuum tube was from plate to heated filament.

297. When a two electrode tube is connected in an alter-

nating-current circuit it functions as a *rectifier*, as *current can only pass through it in one direction.* Alternations in the opposite direction are simply cut off. The well known Tungar rectifier, used for charging storage batteries from an alternating current supply, utilizes a tube of this type. When a two-electrode tube is connected in a receiving circuit we have a sensitive *detector*, with *unilateral* conductivity. If, instead of the plate battery, as illustrated in figure 242, we substitute the antenna, as in figure 241, and oscillations are impressed upon the plate, we have practically duplicated the conditions for receiving when a crystal detector is used, the heated filament taking the place of the crystal and the

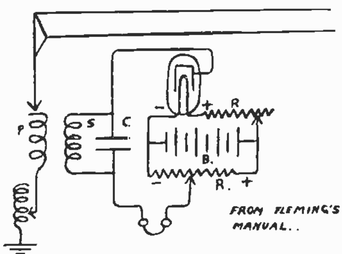


Fig. 240. Diagram of Early Fleming Valve Receiver.

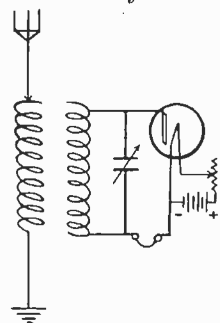


Fig. 241. Two-Electrode Tube with Plate Energized from Antenna.

plate serving as the contact point. The oscillating current is rectified to a one way pulsating current; and, if the received signals consist of damped waves, or interrupted continuous waves, signals will be heard in the telephones. The signals heard will be of about the same volume as those procured with a sensitive crystal, and little has been gained by substituting the tube for the crystal. With the plate battery added, we have this advantage over the ordinary crystal detector—that the tube, when connected with its filament and plate batteries, is also an *amplifier* of the volume of the signals intercepted by the antenna. The signals received are passed through the rectifying tube, as through the earlier forms of detectors. The operation of the telephones and the tuning circuit is exactly the same as with the receiving circuits described in part two of this book. But the direct current from the plate battery is already flowing before the signals are passed through the tube. Because this direct current from the plate battery has no variation to cause the telephone diaphragm to vibrate, we can not hear it. The one way alternations of the rectified current set up in the receiving set by the received signals are *added to the plate battery current;* and the whole, in passing through the telephones, produces a *louder signal* than the received energy

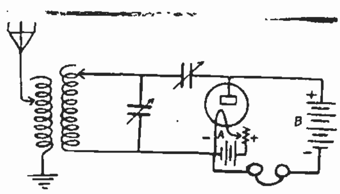


Fig. 242. Fleming Valve Receiver with Separate Plate Battery. (Bucher.)

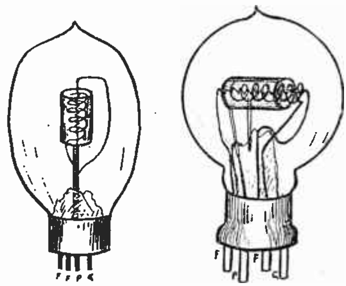


Fig. 243. Three-Electrode Vacuum Tubes.

alone would produce. In figure 240 is shown an early form of vacuum-tube receiving circuit, devised by Dr. Fleming of London. In this the same battery is employed for lighting the filament and supplying the plate current. In figure 242 a modification of this is shown, using a separate battery for the plate. For convenience, the custom of referring to the plate battery as the "B" battery, and the filament battery as the "A" battery, has become universal. The tube detector, like the earlier detectors, simply *rectifies* the incoming signals, and will not cause a sound in the telephones unless there is some *variation of audio frequency.*

298. If the vacuum in the tube is not complete, but there is even a small amount of gas or air in the tube, *ionization* will take place. Ionization is brought about by collisions between the moving electrons and the atoms composing the gas and the consequent disrupting of these atoms into negative electrons and positive ions. This results in an increased flow of current through the gas. While this was at first considered an advantage, it also caused continuous annoyance by burning out the filaments, which could not withstand this excessive current. In extreme cases ionization is evidenced by a *blue glow.* The disrupting of the atoms composing the gas allows a large number of negative electrons to be added to those from the filament, which move to and adhere to the plate. This necessarily leaves free in

the space within the tube a number of positive ions, giving a strong positive charge to the space within the tube. These positive ions are then attracted to the filament with great force by the negative charge of the filament current, and this shock to the filament causes an increased plate current, amounting almost to a flame, which is the cause of the blue glow. Tubes manufactured for radio receiving apparatus are now generally completely evacuated, or at least this is attempted. After they are made, tests show that some of them have not as good a vacuum as others. They are then sorted into "hard" and "soft" tubes, and sold for "amplifier tubes" or "detector tubes." The "soft" tubes, which are not quite evacuated, make more sensitive detectors than the more highly evacuated ones, especially for long-distance reception, although they are less uniform and somewhat more likely to make undesirable noises than the others.

299. Since the invention of the Fleming valve, with the simple construction and the two electrodes, many forms and varieties of tubes have been placed on the market, and called, according to Lieutenant E. W. Stone, of the U. S. Navy, "Audions, electron relays, kenatrons, pliotrons, dynatrons, oscillions, thermotrons and what-not, according to the caprice of their respective inventors." The important point in the development of these tubes is the addition of the *grid*, or third element. This consists of a coiled or crimped wire, which is placed in the tube in such a position that it is directly in the path of the flow of electrons from filament to plate. If this grid is energized with a third battery, generally referred to as a "C" battery, the polarity of this charge on the grid will have a marked effect on the space charge of the tube. *When the grid is charged positively, the positive attraction is increased, and hence the flow of electrons to the plate is increased, resulting in an increased flow of plate current. If the grid is charged negatively, this negative charge will repel the negative electrons emitted from the filament, allowing only a few, which may pass through the openings in the grid, to reach the plate. This reduces the plate current to less than it would be normally. If the grid is negatively charged to the saturation point, the positive*

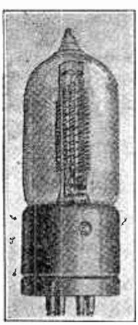


Fig. 244. The VT1, or "J" Tube, Used in the Navy and Signal Corps.

charge of the plate will be completely neutralized, and no current can then flow, although the filament and plate voltages are the same as before. This is sometimes called the "trigger action" of the grid, because it serves as something similar to a trigger in its control of the flow of plate current

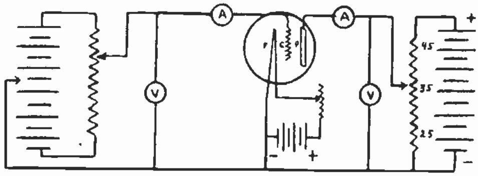


Fig. 245. Laboratory Circuit for Determining Characteristics of a Vacuum Tube.

300. Several characteristic curves, showing different relations of voltage and current, may be made of the vacuum tube. We may make a curve showing the voltage and current of the plate circuit for different temperatures of the filament; or we may make a curve showing the same for the grid with respect to the filament temperature, or a curve showing the plate current for various voltages of the grid when the filament temperature remains constant. The latter is perhaps the most interesting from the operating point of view. It can be seen that the plate current and the grid current depend upon the plate and grid voltages, when the heat of the filament remains the same. The grid voltage variations affect the plate current much more than changes in the plate voltage. It will be noticed, also, that the saturation point of the tube is indicated on the curves. For instance, in figure 247 the sharp bend in the curve comes at the point of saturation, beyond which any increase in plate voltage does not produce an increase in plate current. A number of readings for the curve shown in figure 247 can be made for various grid voltages. If this is done, the point will be reached where the horizontal line on the curve for an increase in grid voltage will coincide with that of the plate voltage, indicating the point of complete saturation for the tube, for both grid and plate voltages. Figure 249 shows a characteristic curve used for determining the grid current at different grid voltages. Three readings are taken for three settings of plate voltage. It will be noticed that the *grid current* decreases—for a given grid voltage—when the

plate voltage is increased, and also that the grid current, due to negative electrons between grid and filament, is zero when the grid has a negative potential, but rises to a few millionths of an ampere when the grid is positive.

301. The vacuum tube does not exactly comply with Ohm's law, as it is generally understood. It may be considered as a variable resistance, with the voltage of the grid acting as a resistance regulator. In the *U. S. Signal Corps Pamphlet No. 40,* we find the following statement: "*The higher the grid voltage, the less is the resistance, and vice versa. For low grid voltages the resistance changes with plate current in a manner similar to a carbon lamp, the resistance of which goes down as the lamp heats up. At high grid voltages it changes as does a metallic filament lamp, the resistance of which increases with increasing current.* This conception of a tube is very helpful in studying its operation, especially in transmitting equipment." The relative changes of current and voltage within the tube, when one factor remains constant, constitute what are called the *constants* of the tube. The relative effects of the plate voltage and grid voltage *upon the plate current* indicate a characteristic condition which is known as the *amplification coefficient* of the tube. There is a *capacity* between the elements within the vacuum tube, this being especially noticeable at high frequencies, and having definite effects upon its operating characteristics. The combined capacity between the plate and filament and the plate resistance constitute the *internal impedence* of the tube. These may be measured by methods given under the heading of measurements, in chapter 38.

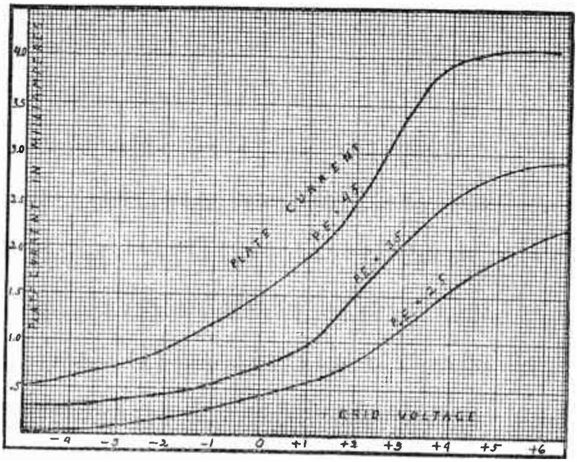


Fig. 246. Characteristic Curve of a Three-Electrode Tube, Showing Plate Current at Different Grid Voltages. This Shows Three Separate Readings with Plate Voltage Set at 25, 35 and 45 Volts.

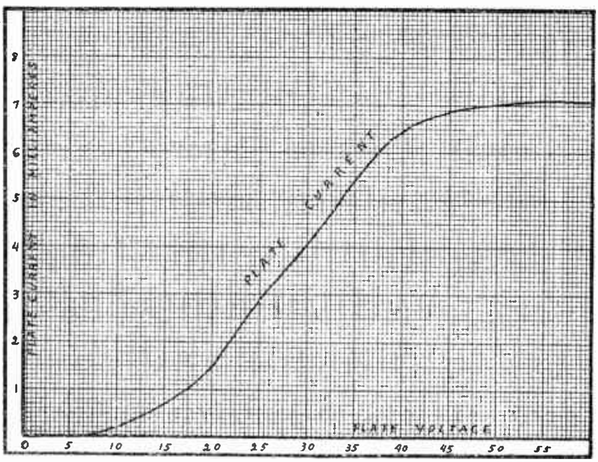


Fig. 247. Curve Showing Plate Current Increase with Plate Voltage Increase, Grid Voltage and Filament Temperature Remaining Constant.

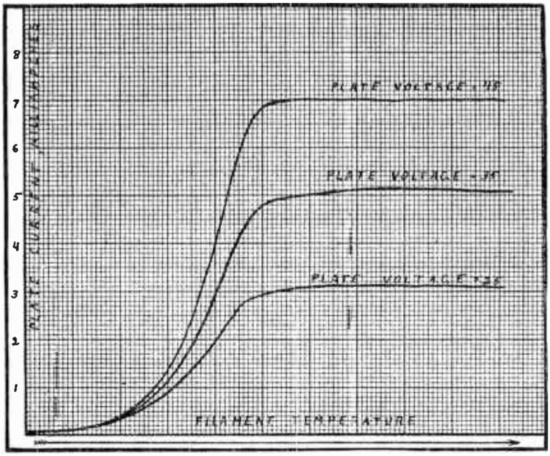


Fig. 248. Curves Indicating the Plate Current at Three Different Plate Voltages, for the Same Increase in Filament Temperature.

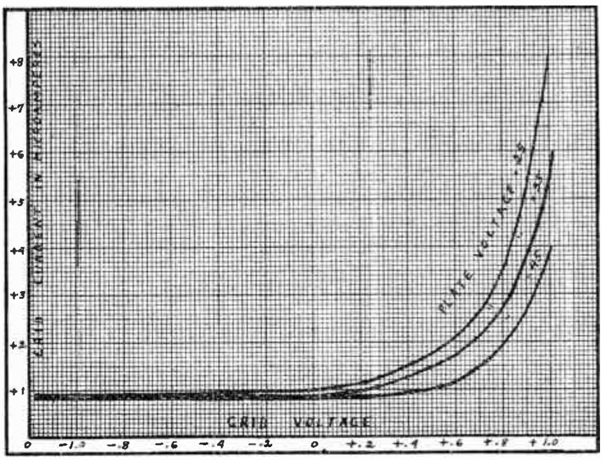
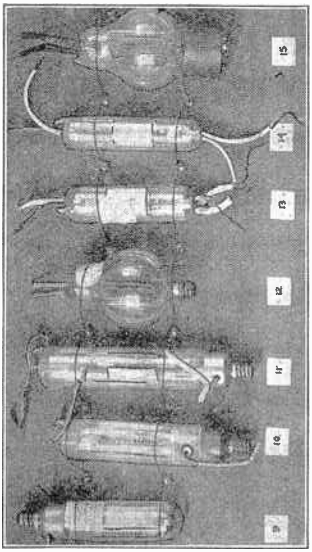
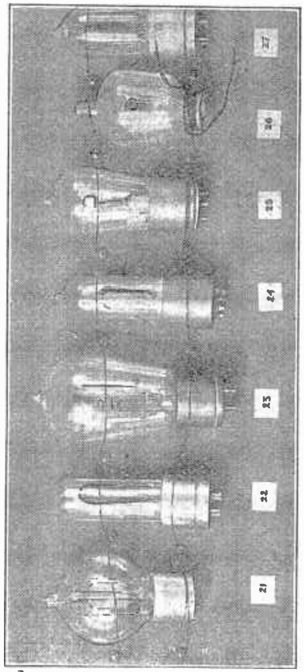
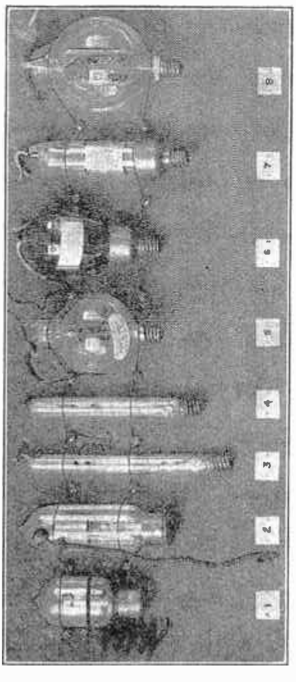
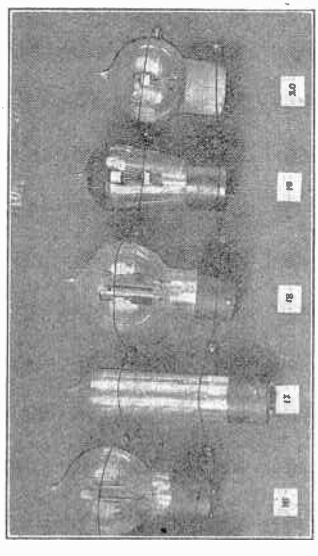


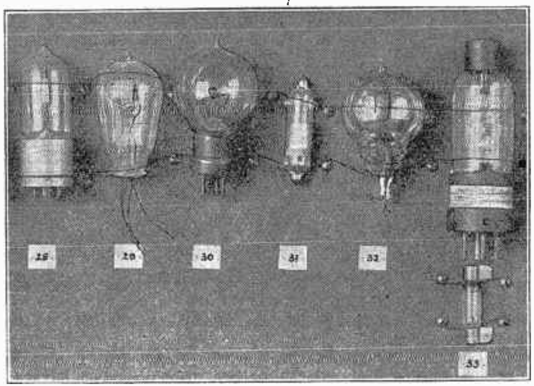
Fig. 249. Curve Showing Grid Current for Various Grid Voltages, with Three Different Settings of Plate Voltage.

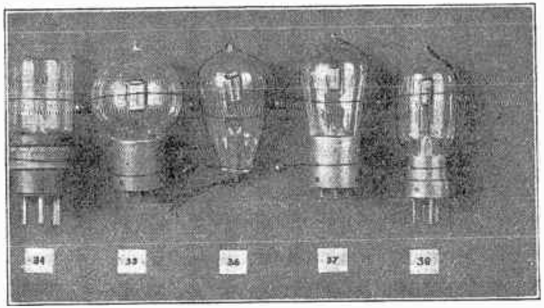












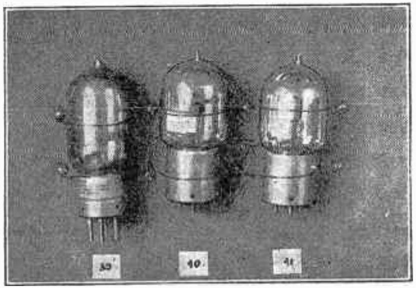


Fig. 250. Collection of Vacuum Tubes Showing Development from Fleming Valve Down to the Standard Form in Use Today. (This collection was made by Lieutenant W. A. Eaton, U. S. N., at the Navy Yard, Washington, D. C. Photograph and key presented to Loomis Radio College by Lieutenant Eaton.)

KEY TO VACUUM TUBE COLLECTION OF LIEUTENANT W. A. EATON

(With grateful acknowledgment to Lieutenant W. A. Eaton, Navy Yard Test Shop, Washington, D. C.)

No.	Origin	Filament Construction support.	Grid Construction support.	Plate Construction support.	Base and Connections	Remarks
1	British Marconi.	Carbon.	None.	Cylinder direct on stem.	Two point bayonet side lead.	Fleming valve, two-element.
2	British Marconi.	Carbon V Glass rod.	None.	Cylinder wire.	Two point bayonet side lead.	Fleming valve, two-element.
3	Early Experimental.	Two carbon.	Ring wire.		Miniature two point side lead.	
4	Early Experimental.	Carbon.	Ring wire.	Wire.	Miniature two point side lead.	
5	Hudson De Forest.	Carbon pasted spare.	Ziz zag double seal.	Double wire supports to seal.	Miniature double end seal.	Supplied with early De Forest apparatus.
6	Wireless Specialty. (Pickard).	Carbon.	Perforated sheet in from 2nd seal.	Bent sheet wire from second sheet.	Two point skirted miniature double end seal.	Crude experimental.
7	De Forest tubular Audion.	Tungsten V.	Spiral heavy copper support one end only.	Aluminum cylinder fits bulb.	Miniature double end seal.	Used in Navy.
8	Later Hudson De Forest	Carbon pasted spare.	Zig zag wire, glass rod support.	Flat unsupported.	Miniature double end seal.	Used in Navy.
9	Moorehead relay.	Tungsten.	Fine wire wound on glass frame.	Continuous bent Aluminum supported on grid frame.	Skirted miniature single end seal wires from base.	Commercial.
10	De Forest.	Twisted oxide V spring support.	Fine wire wound on glass frame side tap.	Aluminum, glass supports end seal.	Plate from end seal grid from side tap.	
11	Ditto.	Ditto.	Ditto.	Ditto.	Plate from end seal grid through base.	
12	Western Electric.	Twisted Oxide V loop support.	Spot welded fine grid glass stem.	Flat, Double cross breaks.	Miniature base, double end seal.	Used in Navy. Western Electric Co. V. tube.
13	Moorehead.	Tungsten V three lead support.	Heavy copper helix one end support.	Aluminum cylinder fits tubes.	No base, one end P. F. other G. F. F. (two legs to F).	Electrically very similar to (7).
14	De Forest.	Tungsten straight.	Heavy copper helix one end support.	Aluminum cylinder fits tube.	No base, one end P. F., other G. F.	Similar to (13).

KEY TO VACUUM TUBE COLLECTION OF LIEUTENANT W. A. EATON—Continued

No.	Origin	Filament Construction support.	Grid Construction support.	Plate Construction support.	Base and Connections	Remarks
15	Western Spiral Base.	Twisted side V loop support.	Welded cross braced to glass rod.	Two flat braced both ends.	Three points base second seal P. & G	A. W. E. Co. V. tube (12 fitted to Navy Three-point tube).
16	De Forest.	Twisted (coated) U	Fine wound on glass frame.	Two aluminum anchored to same glass frame.	Three point base.	Standard.
17	De Forest.	Tungsten V anchored.	Ditto.	Ditto.	Ditto.	Ditto.
18	Western Electric.	Twisted coated V anchored.	Fine wound on glass frame, metal guards.	Two flat anchored at four points to glass frame.	Three point.	Standard.
19	General Electric.	Tungsten double spiral headlight.	Double spiral.	Small, thimble shaped.	Three point.	Standard pliotron.
20	General Electric.	Ditto.	Ditto.	Ditto.	Ditto.	Standard differs from (19) in shape of bulb details of seal and supports of G. & P.
21	Western Electric.	Twisted coated V anchored.	Fine welded supported to glass stem.	Double braced to glass stem.	Two point metal thimble wax filled.	Standard (D).
22	Moorehead.	Tungsten straight.	Rather heavy wire wound on glass copper guards.	One piece aluminum anchored by glass frame.	Four point metal base micarta installation.	Similar to (G) improved.
23	General Electric	Tungsten V anchored.	Very fine, wound on glass frame close to filament.	Zig zag of stiff fine wire anchored top and bottom spaced wide.	Four point.	Amplifier bulb special.
24	Western Electric.	Twisted coated V anchored.	Fine welded, supported to glass stem.	Double braced to glass stem.	Four point metal micarta and wax seal.	(21) with change of bulb and base.
25	General Electric.	(See 19)			Four point metal and porcelain.	C. G. 890.
26	British Osram (G. E.).	Straight Tungsten, bow support.	Helix bow support.	Cylinder (nickel) single support traverse.	Fake seal miniature base all leads to tip seal.	One form of the foreign tube.
27	Western Electric.	Twisted coated V anchored F lava block crossed leads.	Stamped course one piece welded braces anchored to lava block.	Welded double flat corrugated clamped on stem holds lava block.	Four point metal, wax insulated.	CW 933 or J tube (S. C. V. T. 1).

KEY TO VACUUM TUBE COLLECTION OF LIEUTENANT W. A. EATON—Continued

No.	Origin	Filament Construction support.	Grid Construction support	Plate Construction support.	Base and Connection	Remarks
28	Western Electric.	Twisted oxide coated very fine two parallel sides anchored by U mica insulated V spring leads.	Medium fine wound and welded to wire frame, spaced close to filament.	Flattened cylinder welded to wire supports, which support G. & F.	Four point wax insulated (standard).	V. T. 3 not Navy standard ("Wash Boiler Plate").
29	Built by K. C. Underwood, Edison Lamp Works, Harrison, N. J.	Carbon.	Wire on harp frame.	Single, flat, unanchored.	Unbased regular lamp seal.	Historical; probably the first valve made in regular lamp works.
30	Fotos French.	Straight Tungsten.	Helical supported 2 ends.	Cylindrical Nickel, center support.	Four prong (French British Standard).	The bulb for which most foreign apparatus was built.
31	British	Straight Tungsten Spring anchor.	Wire mesh cylinder insulated from filament leads.	Cylinder fits tube.	Ends of F. P. & G. at sides. Metal contact caps.	Q tube pat. 4410, used in first stages of British apparatus.
32	U. S. N. Experimental.	Straight (Navy) Tungsten.	Helical turns welded to support.	Cylinder, one wire support axial in bulb.	Round bulb for Four point base.	First step of new standard.
33	German.	U carbon (?) Ballast tube to go in series.	Flat spiral glass supports parallel to P.	Circular disc glass supports.	Filament leads from upper seal to large Four-point base.	From captured apparatus.
34	German.	Straight Tungsten.	Stamped and bent and welded cylindrical braced medium fine.	Bent cylindrical braced.	Large Four-point base.	A well-made copy of (26) (30).
35	Sample submitted by Moorehead.	Double spiral Tungsten.	Double spiral course, close to plate 2 anchors.	Cylinder double anchored.	Four-point metal and micarta.	Rejected step toward standard.
36	Sample Westinghouse.	Straight Tungsten spring support.	Helix.	Cylinder wire support.	Unbared.	Element weak mechanically.
37	General Electric.	Tungsten V anchored.	Helix supported at ends.	Cylinder, two welded supports.	Four-point metal and comp. 5 leads.	Redesign C. G. 890 two ends for grid for heating.
38	Moorehead	Straight Navy Tungsten.	Helix turns welded to anchor.	Cylinder welded to L support.	Four-point base British type.	Sample submitted shows color produced by phosphorus process of exhausting.
39	Ditto.	Ditto.	Ditto.	Ditto.		
40	Moorehead	Straight end supported.	Helix turns welded to support.	Cylinder horizontal L support welded.	Four-point metal and composition. Bulb shape changed.	Proposed as standard horizontal plate and method of seal rejected.
41	Moorehead.	Ditto.	Ditto.	Cylinder vertical L support welded.	Four-point metal and composition P. & G. at opposite sides of seal.	Adopted as standard. S. E. 1444.

CHAPTER 33

The Three-Electrode Vacuum Tube as Detector and Amplifier

Vacuum Tubes in Receiving Apparatus—Detector—Without and With Grid Condenser and Grid Leak—Rheostat—Potentiometer—C Battery—B Battery—Grid Bias Connections—Tables of Receiving-Tube Characteristics—External Heterodyne, Early and Modern—Production of Beat Note — Regeneration — Variometer — Reinartz Circuit — Flewelling Circuit—Spider-Web Coils

302. When the three-electrode vacuum tube is connected in a receiving circuit so that plate current can flow, and high-frequency current is conveyed to the grid by way of the antenna and tuning circuit, we have the most sensitive detector yet used in practical receiving. Aside from the tube, with its batteries, the fundamental receiving circuit is the same as that used with the crystal detector, and tuning is done by varying inductance and capacity. The plate

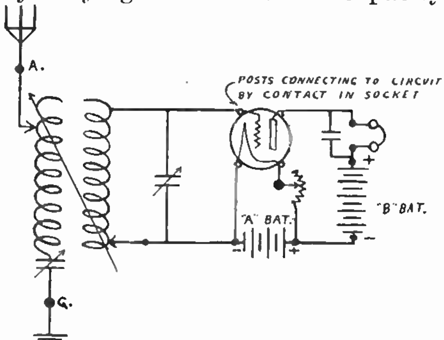


Fig. 251. Fundamental Diagram for Three-Electrode Tube Receiver.

circuit, with the telephones and "B" battery, is sometimes referred to as the *tertiary* circuit to distinguish it from the secondary and primary tuning circuits. When the receiving circuits are properly adjusted to respond to the wave length of the intercepted signals, and alternate and positive charges are produced on the grid by these oscillations, there is an increased flow of plate current each time that the grid becomes positive; and when the grid becomes negative there is a decrease of plate current below that which would flow if this negative charge were not present on the grid. This means that we have variations of plate current over a much wider range than was possible

Fig. 252. Three-Electrode Tube Socket, Showing How Contact is Made.

with the two electrode tube. The increase of plate current when the grid is positively charged is greater than the decrease when the grid is negative, and the total result, when the tube is used without a condenser in the grid, as in figure 251, is an increase in plate current when signals are being received. The tube, in addition to its action as a rectifier, is functioning as a *relay,* operated by the feeble energy of the received signals impressed upon the grid, to control and cause corresponding fluctuations in the plate current. These variations in the plate current, then, in passing through the telephone windings, *reproduce* the received signals in the telephones. It can be seen that *the plate current becomes pulsating* under the relay action of the grid. It is sufficiently pulsating to pass through a transformer. If the plate current is too large for the characteristics of the tube, due to too high filament temperature, the variations of grid voltage may be overpowered and no signals heard, or they may be weak. This is known as "flooding" or "paralyzing" the tube. The tube will probably be damaged if such a condition is allowed to exist for any length of time.

303. In some cases it has been found an advantage to use a battery in the grid circuit of a detector tube. This is known as a "C" battery. It provides means for adjusting the potential of the grid, so that the tube can be operated on any desired point of its characteristic curve. When used in this way with a detector tube, the C battery is connected to the grid through a "potentiometer," or voltage divider, as shown in figures 253 and 276. It can be seen that when the grid potential is zero, for any given plate voltage a certain plate current flows. This is known as the normal plate

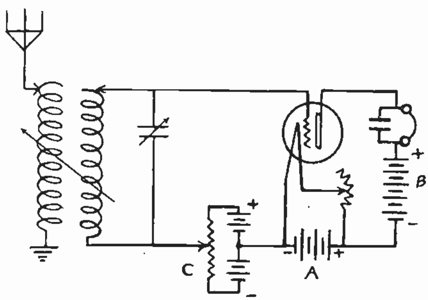


Fig. 253. Three-Element Tube Receiving Circuit with "C" Battery.

current. With the C battery in series with the grid, and the radio-frequency alternating potential of the signals superimposed upon the circuit, causing plate current variations, the amount of *change* in plate current may be varied by varying the grid connection to the C battery, and one particular adjustment found which will give best results, indicating that the tube is performing on the most sensitive point of its characteristic curve. If the grid battery is adjusted so as to place a negative potential on the grid, the plate current will be somewhat suppressed, which will give a greater range of possible change in the increase direction when signals are intercepted. It is not the amount of plate current, alone, passing through a tube, which makes it perform most efficiently as a *detector,* but the amount of *variation* which can be made in the plate current.

In receiving sets consisting of a combination of vacuum-tube detector and amplifier a C battery is sometimes employed in the grids of the audio-frequency amplifier tubes without variable resistance; but *in detector circuits a condenser is generally connected in series with the grid,* as in figure 254. The action of this is generally believed to be as follows: When no signals are being received, the normal flow of direct plate current takes place from filament to plate. Putting the condenser in the grid insulates the grid circuit from the plate current. When signals are intercepted by the antenna and conveyed to the receiving set, an oscillating current is set up in the circuit consisting of the secondary of the receiving transformer and the variable condenser, charging the condenser in series with the grid with alternately positive and negative potentials. This produces alternately negative and positive charges on the grid. When the grid is negative it repels the negative electrons of the filament emission, reducing the plate current; and when the grid becomes positive, it increases the flow of electrons to the plate more than in a circuit like figure 251, because the grid can not rob the plate as in the latter. When one plate of a condenser receives a positive charge, the other plate must necessarily become negative due to the static strain through the dielectric. When the grid condenser plate nearest to the grid becomes positive, causing the grid to be positive, an oscillation can flow downward through the secondary of the receiving transformer and across the space between the filament and the grid, due to the positive attraction of the grid, increasing the total current through the tube, and probably charging the grid condenser on the side nearest to the grid. When the grid becomes negative, the oscillation in the opposite direction is rectified. This has the effect of causing the grid to gradually accumulate negative electrons. Each time that the grid is positive and attracts negative electrons from the filament, some of the electrons adhere to the grid while others pass over to the plate. When the grid is negative these electrons do not leave the grid, but continue to pile up there until there is a perceptible decrease in the plate current. When the plate current is thus decreased the magnetism in the telephone windings is reduced so that the diaphragm is released with a snap, causing sound vibrations. With the grid condenser

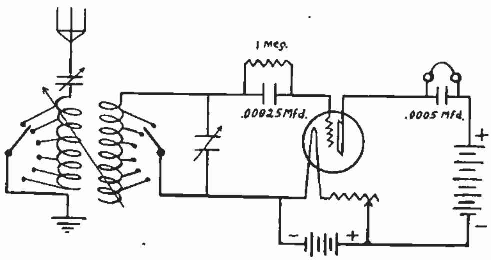


Fig. 254. Receiving Circuit Employing Grid Condenser and Grid Leak.

connected in series with the grid, then, the radio-frequency pulsations of any signals having audio-frequency variations are *reduced to audio frequency by the action of the grid condenser*, by the same "running together" process described in paragraph 260, where it was explained that this was performed by the telephone diaphragm. *The output of a tube having a condenser in the grid lead consists of pulsations of audio frequency*, and the radio-frequency pulsations have been destroyed. These *audio-frequency* pulsations then pass through the telephone and actuate the diaphragm. Generally the intensity of the sound vibrations produced by this releasing of the diaphragm is greater than that caused by the other method, which causes the diaphragm to vibrate by drawing it still closer toward the magnets. When a tube contains gas, or is a "soft" tube, the negative charge may leak off through the gas, so that at the end of each wave

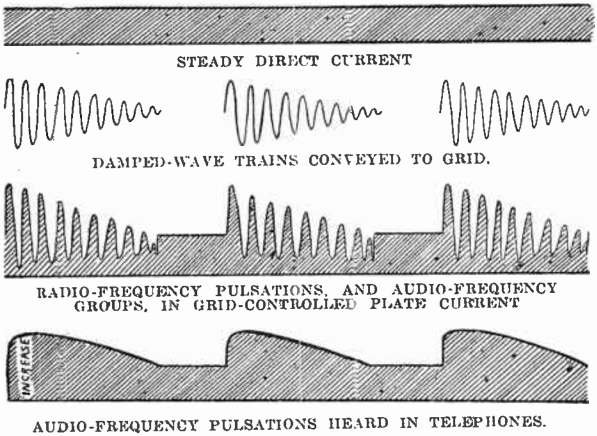


Fig. 255. Influence of Grid Potential on Plate Current.

train, or group of interrupted continuous waves, or in accordance with the modulation of voice or music, the tube will automatically adjust itself for the next audio-frequency variation. With more highly evacuated tubes, however,

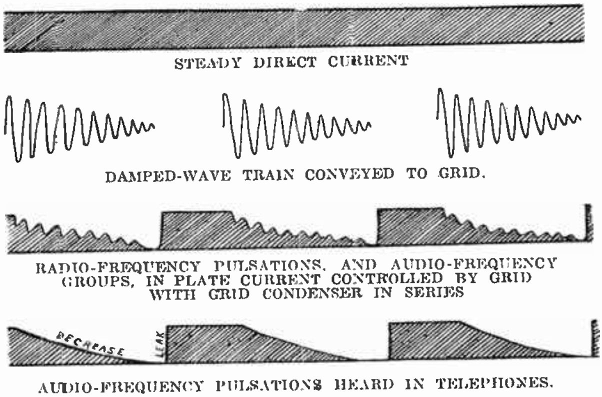


Fig. 256. Effect of Signals on Plate Current with Grid Condenser.

this does not take place, and a leakage path for the release of the negative charge is provided by placing a high resistance in shunt around the grid condenser, or from grid to filament. This is known as a *grid leak*. It may consist of a piece of high-resistance wire, a strip of high-resistance metal, a graphite pencil mark, or of a block of carbon or small carbon discs arranged so that the resistance can be varied by the pressure exerted upon them. The resistance

Fig. 257. Metal-Strip Grid Leak.

Fig. 258. A Variable Grid Leak.

may be from ½ megohm to 5 megohms. Variable grid leaks, when properly constructed and operated, will vary the strength of the signals greatly on different adjustments, and assist considerably in tuning the apparatus. In regenerative circuits this may be used to determine an oscillating condition which is necessary for the reception of uninterrupted continuous waves. The variable leak can be adjusted until a slight hiss indicates that the tube is oscillating. For broadcast reception or spark signals a slight adjustment off this point must be made. When no signals are coming in, oscillating may be determined by tapping the grid leak, or the bare wire connection to the grid terminal of the tube, with the finger. If the tube is oscillating a dull click will be heard in the telephone receivers. The capacity of the

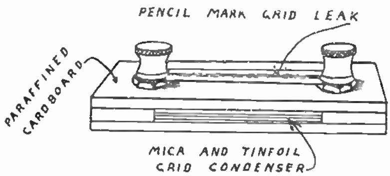


Fig. 259. Mica and Tinfoil Grid Condenser with Lead-Pencil-Mark Grid Leak.

Fig. 260. A Standard Type of "B" Battery with Taps, Providing a Range of from 18 to 45 Volts.

grid condenser is usually about .00025 microfarad, or .0005, depending upon the characteristics of the tube with which it is used. (See paragraph 305.)

304. The filament source of power for the standard type of tube is usually a six-volt storage battery, controlled by a small rheostat. In some cases the filaments are supplied with stepped-down alternating current taken from a city power line.

Tungsten-filament tubes give a brilliant white light; but coated filaments such as the "J" tube, give only a dim light, and the filament should not be heated above a dull red. The filament of the latter is made of platinum coated with barium oxide, giving a free emission of electrons at low temperature.

Some of the more elaborate receivers have a filament-battery voltmeter and a plate-current milliammeter mounted on the panel. The customary plate supply for vacuum-tube receiving sets consists of a number of flash-light dry cells connected in series and imbedded in sealing wax. Where convenient to charge them, small storage batteries are often used.

During the World War a small tube was developed, which

Fig. 261. An "A" Battery Rheostat with Vernier Attachment Consisting of One Piece of Resistance Wire.

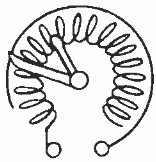


Fig. 262. Diagram of Rheostat at Left.

will operate on one dry cell. This was informally christened the "peanut" tube. Since then this idea has become very popular, and several types of tubes are now in use operating on dry cell filament supply, although the volume of signals obtained by this method is seldom equal to that which

Fig. 263. Aeriotron WD-11.

Fig. 264. Radiotron UV-199.

Fig. 265. "Peanut" Tube in Small Socket.

would be obtained with the same apparatus operated with standard tubes with more filament power. One of the first of these dry-cell tubes was the Aeriotron WD-11, manufactured exclusively for use in the Westinghouse Aeriola Senior receiving set. This tube has a smaller than standard base, with prongs of unequal size. The WD-12, which came out later, is practically the same tube except that it has shorter prongs. These tubes operate on 1.5 volts for the filaments with a filament current of .25 ampere. The Radio Corporation of America placed on the market a smaller tube, called the Radiotron UV-199, which is 3½ inches in length and 1 inch in diameter. It operates on three ordinary dry cells, or flash-light batteries, at 4.5 volts and .06 ampere filament supply. The filament is composed of a composition containing a large percentage of thorium oxide and has a longer life than previous types of filaments. A thirty ohm rheostat should be used in the filament supply of this tube. The use of a 10-watt 110-volt tungsten lamp placed in series with one lead of the plate battery is also recommended as a protective resistance. The resistance of tungsten increases with heat, so if an overload should occur, the increased resistance of this lamp would protect the tube. Another small tube has a plate consisting of a coil of wire outside of the glass. The laboratory of the U. S. Signal Corps, where tests are made of all tubes, has pronounced tubes of this type with external wire coil "plates" when used for detectors, "About as sensitive as a crystal detector." However, regenerative circuits, which will not operate with crystal detectors, can be used with them.

The current required for the plate battery in detector circuits is from 0.1 to 10 milliamperes, and the potential from 18 to 45 volts. It will be noticed that the plate current is small compared to its voltage. Also, as the grid current is exceedingly small and the *voltage* of the grid controls the *action* of the tube, the vacuum tube may be considered a *voltage*-operated device.

305. The first practical receiving tube to appear on the market was the De Forest "ultra audion." This was in 1914.
wire outside of the glass, operates on three dry cells, or on a
sistance of this lamp would protect the tube.

Another small tube with the plate consisting of a coil of
Several of the early De Forest tubes, or *audions,* as he called them, are shown in Lieutenant Eaton's collection, illustrated in figure 250. Several types of De Forest tubes, known as VT's, were used extensively in the U. S. Signal Corps. Later types, now on the market, are the DV-2 and DV-3. These use much less filament power than the older types, and have a higher and more uniform degree of vacuum. The De Forest audion, DV-2, is a hard tube, which can be

used for either detector or amplifier, and draws one quarter of an ampere filament current, at six volts. The DV-3 draws but sixty-five hundredths of an ampere filament current, and is made to operate on three volts dry cell power. It has a standard size base.

In the Army and Navy the coated-filament "J" tube, illustrated in figure 244, is used almost exclusively for standard receiving sets. Commercially, besides the De Forest audions, the Cunningham tubes and Radiotrons are prominent. The Radiotron UV-200 is a soft tube used as a detector with 22½ volts plate potential; and the Radiotron UV-201-A is a hard tube which may be used for a detector with a plate potential of 45 volts, or as an amplifier with 90 to 100 volts on the plate. A filament rheostat of about 6 ohms is used with the UV-200 and from 20 to 30 ohms with the 201-A. The accompanying table, given out by the manufacturers of the Radiotrons, is useful in constructing and installing receiving apparatus.

The Cunningham tubes are designated as C-300 for the soft detector tube, C-301-A for the hard amplifier tube, and C-11, C-12, C-299 for the dry cell tubes. The table for characteristics of the radiotrons will apply in a general way to the Cunningham tubes. The latter are made by the General Electric Company. The Radio Corporation of America has followed their type UV tubes with types called UX. These are described in the Tables of Radiotron Characteristics on pages 342 and 837. Cunningham tubes with different bases and longer prongs to fit Navy Standard sockets are known as CX tubes.

Fig. 266. Radiotron UV-200.

306. The manner of connecting the grid return to the filament battery terminals is important for obtaining best results. While the grid condenser in the detector circuit insulates the grid circuit from the flow of electrons, it is a movement of these, back through the grid leak to the filament, which causes the operation as a detector of the combined vacuum tube, grid condenser and grid leak. Therefore the voltage of the grid, to obtain best results as a *detector*, must be such that there will be a flow of grid current through the grid leak, but this must be only sufficient to operate the tube as a detector, and not enough to rob the plate. Hence a *hard tube used as a de-*

tector, with grid condenser and grid leak, should have its grid return connected to the positive side of the A battery, encouraging the flow of grid current and making it sensitive as a detector. *A soft tube used as a detector with grid condenser and grid leak should have its grid return connected to the negative side of the A battery, as in figure 254.* This is because, on account of the presence of gas in the bulb, the input impedence of this tube is much lower than that of the more highly exhausted tube, and grid current will flow at a much lower potential. With the grid condenser and grid leak, the grid bias is determined by the voltage drop through the resistance of the grid leak, and the polarity of the bias is that obtained through this resistance,

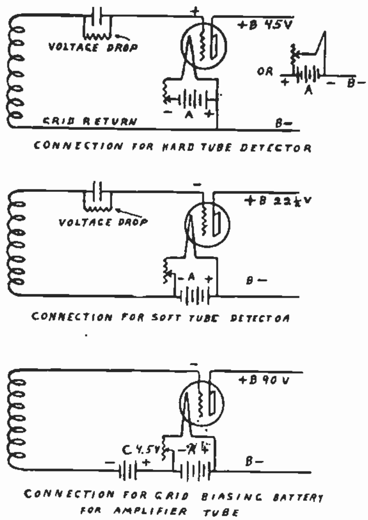


Fig. 267. Proper Grid Return Connections for Detector Tubes and Grid-Biasing Battery Connection for Amplifier.

the varying polarity of the received electromagnetic waves being superimposed upon the grid bias voltage by means of the grid condenser. When the grid condenser and leak are not used, either a hard or soft tube used as a detector is connected with a grid return attached to the negative side of the A battery, as in figure 251. When a hard tube is used for an *amplifier, grid current is undesirable,* as it causes distortion of the signals, interfering with the faithful reproduction of the sounds. This may be overcome by the addition of the grid biasing battery. In figure 268 is shown a simple detector circuit, using a soft tube and two stages of amplification, or "magnification," as it is called in England. A grid biasing battery is used, connecting the grids in parallel to a single 4.5-volt flash-light battery. As this permits wide *variations* of plate current, on a lower point on the characteristic curve of the tube than is the case when the grid bias is not employed, the total plate current consumed is less than without this bias. In other words, at the same time that the grid, acting as a relay, is giving *magnified audio-frequency variations*, it is, under the control exerted by the biasing battery, doing this with a minimum of distortion, and is *conserving the power of the plate battery.*

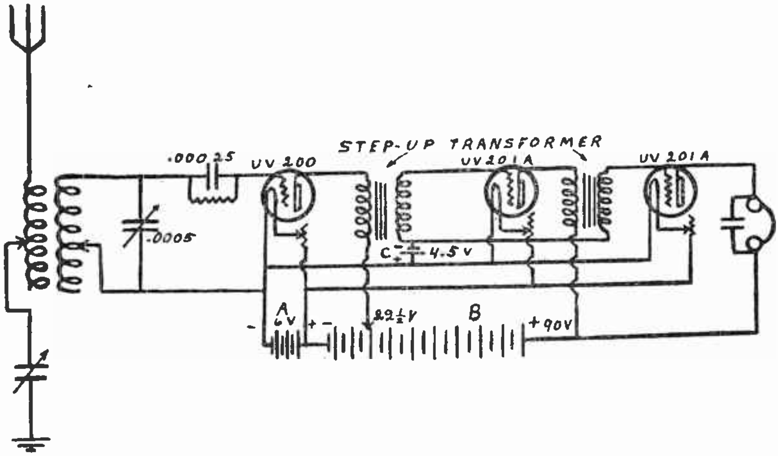


Fig. 268. Plain Detector Circuit with Two Stages of Audio-Frequency Amplification.

Fig. 269a. Cunningham Detector, CX-300-A, with long-prong base.

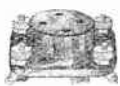


Fig. 269b. Socket for "The New X Tubes." This will accommodate either dry-cell or storage-battery tubes.

Note: For table of Radiotron and Rectron Characteristics see page 337.

RADIOTRON CHARACTERISTICS

(Radio Corporation of America)

Radio-trons	Output	Filament Circuit Data			Plate Voltage		Dimensions Overall		For Detection		Plate Impedance (Approximate) in Ohms	Amplification Constant (Approximate)	Mutual Conductance in Micro-Mhos	Plate Current in Milliamperes (With Zero Grid)	
	Watts (Rated)	Battery Source Voltage	Filament Terminal Voltage	Filament Current	Detector	Amplifier Except Notes	Height Maximum	Diameter Maximum	Grid Leak Megohms	Grid Condenser Mfd				Plate Voltage	Plate Current
WD-11	....	1.5	1.1	0.25	20 to 45	40 to 100 see Note (2)	4 9/16"	1¼"	2 to 3	.00025	19,000 at 40 Volts 17,000 at 80 Volts	6.5	340*	20 40 80	0.3 1.2 3.9
WD-12	....	1.5	1.1	0.25	20 to 45	40 to 100 see Note (2)	3 15/16"	1¼"	2 to 3	.00025	19,000 at 40 Volts 17,000 at 80 Volts	6.5	340*	20 40 80	0.3 1.2 3.9
UV-199	....	4.5	3.0	0.06	20 to 45	40 to 100 see Note (3)	3½"	1"	†† 2 to 9	.00025	18,500 at 40 Volts at Zero Grid 16,000 at 80 Volts with minus 4.5 Volt Negative Grid	6.25	340*	20 40 60 80	0.25 1.1 2.4 3.9
UV-200	....	6.0	5.0	1.0	15 to 23.5	....	4 5/16"	1¾"	½ to 2	.00025 to .0005	9,000	....	....	Detector: 0.25—1.0	
UV-201-A	....	6.0	5.0	0.25	20 to 45	40 to 120 see Note (1)	4 5/16"	1¾"	†† 2 to 9	.00025	16,500 at 40 Volts at Zero Grid 12,500 at 100 Volts with minus 6 Volt Negative Grid	8.0	485*	40 60 80 90 100	1.0 2.6 4.8 6.0 7.5

Note 1 UV-201-A		Note 2 WD-11 and WD-12		Note 3 UV-199	
Plate Voltage	Negative Grid Bias Voltage or "C" Battery	Plate Voltage	Negative Grid Bias Voltage or "C" Battery	Plate Voltage	Negative Grid Bias Voltage or "C" Battery
40 60 80 100 120	0.5 to 1.0 1.0 to 3.0 3.0 to 4.5 4.5 to 6.0 6.0 to 9.0	45 60 80 to 100	0 1.5 3.0	40 60 80 100†	0.5 to 1.0 1.0 to 3.0 4.5 to 6.0 6.0 to 7.5

Note: These figures on Impendance, Amplification Constant, Mutual Conductance do not apply when tube is oscillating.

Note: All of above values are based on approximate averages taken over a long period of time. Individual tubes may vary somewhat from figures shown.

Note: The Amplification Constant in itself is not a direct measure of the amplification given by the tube. The mutual conductance more nearly represents the amplification given in ordinary circuits.

* Mutual Conductance Values are at 40 Volts on Plate and Zero Grid.

†This voltage is not recommended for ordinary service. 80 volts (or four 22½ volt blocks) should not be exceeded except in very special cases.

††A grid leak resistance between two and five megohms is satisfactory for average work. A resistance between five and nine megohms is somewhat better for very weak signals.

SUPPLEMENT TO TABLE OF RADIOTRON CHARACTERISTICS.

UX-200, same as UV-200, but having long prongs to fit Navy Standard Socket.

UX-201-A, same as UV-201-A, but having long prongs to fit Navy Standard Socket.

UX-199, same as UV-199, but having long prongs.

WX-12, same as WD-12, but having long plongs.

UX-112, amplifier to be used in place of UV-201-A.

UX-210, amplifier for last stage audio, for loud speaker volume.

UX-120, dry cell amplifier for last stage audio, loud speaker volume.

TABLE SHOWING RESISTANCE AND POWER OUTPUT OF SOME IMPORTANT TUBES.

(Compiled by Keith Henney, Director Radio Broadcast Laboratory, Radio Broadcast, December, 1925.)

Tube	Use	Plate Volts	Grid Volts	Plate Res.	Power Output Watts
WD-11	Amplifier Detector	90	4.5	14000	.0057
UV-199	Amplifier Detector	90	4.5	15000	.0066
UV-201-A	Amplifier	90	4.5	12000	.0135
UX-112	Detector Amplifier	135	9.0	11000	.058
		90	6.0	8800	.033
		112.5	7.5	8400	.054
		135	9.0	5500	.118
		157.5	10.5	4800	.185
UX-120	Amplifier	135	22.5	6600	.101
216-A	Amplifier	135	9	6000	.059
UX-210	Amplifier	90	4.5	9700	.015
		135	9	8000	.071
		157.5	10.5	7400	.105
		250	18	5600	.41
		350	27	5100	1.08
		425	35	5000	1.84
Daven MU-6	Amplifier	120	7.5	6100	.0625
Cleartron	Amplifier	120	7.5	6260	.0312
Goldentone	Amplifier	120	7.5	5570	.058

307. The receiving circuits illustrated in figures 251, 254 and 268 will respond only to damped-wave trains, or to continuous waves which have been interrupted, or modulated by voice or music. While continuous waves might be intercepted by the antenna, conveyed to the receiving circuits, rectified and amplified, *nothing would be heard.* The telephone diaphragm would simply adhere to the magnets and could not vibrate. By providing some local method of breaking these waves into audio-frequency groups they can be "detected." This may be done by various types of mechanical interrupting devices—which are taken up in chapter 37. However, the method most employed for this purpose is the production of a beat note by means of heterodyne apparatus. Heterodyne is a combination of two Greek words meaning *another force,* where force is the cause of motion or acceleration. In this case the other force consists of a locally-generated alternating current of a different frequency from the received signals. The basis of this idea appears to have been discovered and first applied by Fessenden in 1905. It has had a wide variety

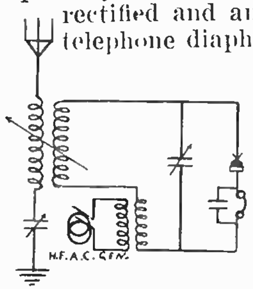


Fig. 270a. Heterodyne with Crystal Detector.

of applications. In its earliest stages a low-powered high-frequency alternator was used as the source of local alternations. This was generally transformer coupled to either the antenna circuit or the secondary circuit of the receiving set.

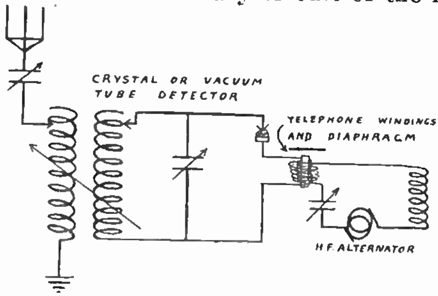


Fig. 270b. Heterodyne Employing Telephone with Double Winding.

Another method, described in Lauer & Brown's *Engineering Principles,* consists of the use of a telephone with a double winding. The local alternating current is run through windings which are placed over the usual telephone windings. Beat note fluctuations in the current cause the telephone diaphragm to vibrate, and the continuous-wave signals are

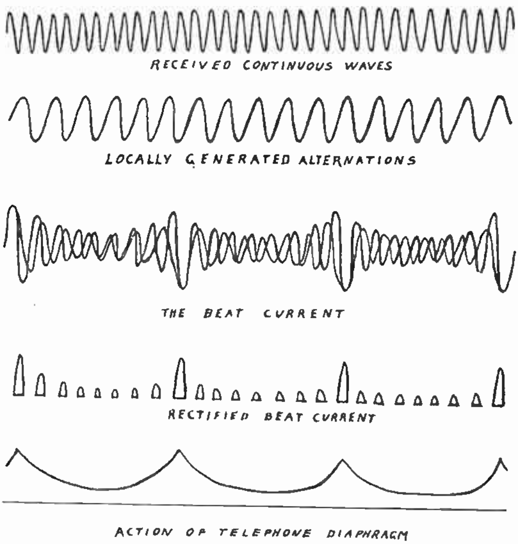


Fig. 271. Illustration of the Development of Beats.

heard at the *pitch* corresponding to the *beat frequency.* Since the discovery of the regenerative principle, the local oscillations are generally produced by vacuum-tube oscillators. Figure 271 shows how the beats are produced when the local oscillations are superimposed upon intercepted continuous-wave signals. The overlapping cycles travel through the circuit at variance, but unite periodically, increasing the energy of the oscillation; and a *beat note* is heard in the telephones. Something similar happens when

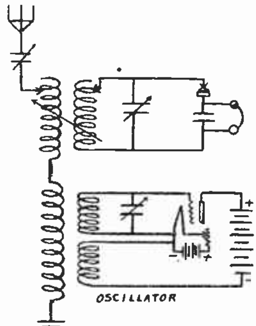


Fig. 272. Crystal Detector with Vacuum-Tube Heterodyne.

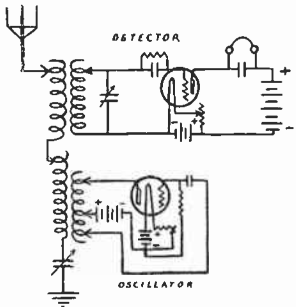


Fig. 273. A Vacuum-Tube Receiver with "External Heterodyne."

two tuning forks of nearly the same pitch are struck at the same time, and allowed to vibrate until their natural inertia causes them to stop. A distinct beat can be heard, caused by the overlapping of the sound waves issuing from the tuning forks. In the vacuum-tube receiving circuit equipped with a grid condenser the pulsations in the telephone would be in the opposite direction; but the heterodyne principle is the same in either case. The heterodyne has several advantages, aside from producing the beat note for the reception of continuous waves. Perhaps the most important of these is that it also *amplifies* the energy passing through the telephones, as the locally generated current is actually added to that of the received signals. Also, as the note heard is that of the *audio frequency of the beat produced* by the union of the current of the two frequencies. this note is under the control of the operator and can be varied by local tuning, which is sometimes a great convenience in receiving through interference. It has been found that when the beat note is of a frequency to correspond with the natural period of the telephone diaphragm that the tones heard are especially strong. The tuning of the external heterodyne receiving set is rather critical, and on short wave lengths such fine adjustments are required that it is hardly practical for this purpose, unless the super-heterodyne system is used (see chapter 36). For the longer wave lengths usually employed by the long-distance high-powered stations, there is "more room" for tuning, and little difficulty in its operation. The audio-frequency heterodyne is not suitable for damped-wave reception, nor for radio-telephony, as the characteristic form of the incoming signals is lost. However, by tuning the local oscillator to the same frequency as that of the distant transmitter, it is possible to receive non-continuous-wave signals on the same apparatus, with the beat tuned out. Or the power of the external oscillator can be temporarily cut off. Tuning the local oscillator to the same frequency as that of the received signals is called *"homodyne"* reception. One characteristic of the heterodyne system is what is known as its *linear law,* that is, the strength of the signals heard in the telephones is in direct linear proportion to an increase in strength of

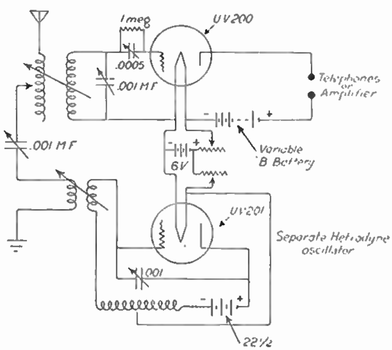


Fig. 274. Two-Tube Heterodyne Receiver. (Radio Corporation of America.)

either the local oscillator output, or the incoming signals. This is in contrast to the tube output when used in simple detection of damped or interrupted continuous waves, where the volume of sound heard is in proportion to the square of the strength of the incoming signals, and where the strongest fluctuations are amplified most and the weaker ones practically lost. In the heterodyne method the same amount of amplification is maintained throughout the entire range of intercepted signals, the weakest fluctuations being amplified as much as the stronger ones; and if a graph be made of this, with signal voltage plotted against telephone response, for a given voltage of the local oscillator, the "curve" will be a straight line. An external heterodyne using the "singing arc" for local oscillations was patented by De Forest in 1911. This employed a vacuum-tube detector.

308. There are certain milestones marking the progress of radio communication as it exists today. One of these was the discovery that *providing certain means for tuning the grid and plate circuits of a vacuum-tube apparatus would cause an increased amplification of the signals, and at the same time could be made to produce local oscillations*—or the *regenerative principle.* This was discovered in 1912 by *Dr. Lee De Forest,* credit for this having been given him in 1924 by the Appellate Court in Washington after several years of litigation, during which period the discovery of the regenerative possibilities of vacuum-tube circuits had been generally accredited by the public to Edwin H. Armstrong. The accompanying sketch played an important part in the proceedings which resulted in the victory for Dr. De Forest. It can be seen that there is an inductive coupling here between the grid and plate of the tube. This was tried as

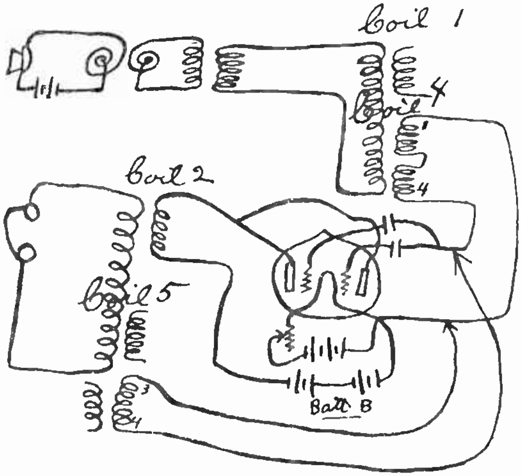


Fig. 275. Original Regenerative or "Feed-back" Circuit, from Dr. DeForest's Note Book for 1912. (Courtesy Radio News, July 1924.)

an experiment in connection with telephone work, and the note states that "When 3-4 of coil 5 is connected, as indicated, to 1-4 of coil 4 get clear tone in phones." The open windings indicated in the coils are accounted for by the fact that standard telephone transformers were used. This feed-back coil, by which energy from the plate circuit is inductively conveyed into the grid circuit has since had wide application in receiving apparatus, and in vacuum-tube telephone transmitting apparatus. It has also had several variations. Any coil in series in the plate circuit inductively coupled to the grid circuit is called a "tickler coil" in this country. The English call it a *reaction* coil.

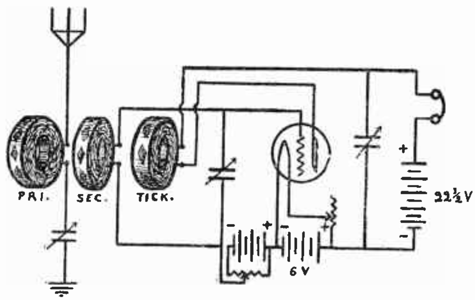


Fig. 276. Popular Adaptation of Tickler Coil, Using Honey-comb Inductances.

The effect of the magnetic coupling between the plate and grid circuits is double. By inducing a small amount of additional energy into the grid circuit, the potential of the grid is raised, causing in turn greater variation in the plate current and increasing the intensity of the sounds heard in the telephones. This is a form of amplification, and it is significant that the oscillating which may be caused by this type of coupling was discovered accidentally during experiments which were being made in an effort to produce a *telephone amplifier*. Something different than was expected was evidenced by a clear *whistle*—the same whistle which has been so unwelcome since, when appearing in receivers where it is not desired. This whistle was caused by local oscillations. By arranging a circuit as shown in figure 276, oscillations may be set up locally and used to produce a *beat note* in the reception of continuous wave signals. This is a self-heterodyne or *"autodyne"* apparatus. The beat is produced as indicated in figure 271, and the external heterodyne oscillator may be dispensed with. The operation of this is as follows: On account of the feed-back between the plate and grid, any slight variation produced in the potential of the grid will produce a corresponding change in plate current, which fluctuation will be conveyed back to the grid

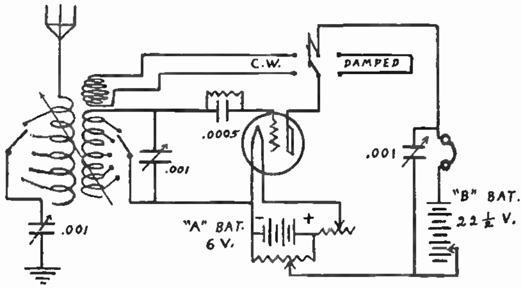


Fig. 277. Regenerative Receiving Circuit, with Switching Device.

circuit by the inductive coupling. When the first pulsation is produced in the receiving circuit, that variation of plate current which is fed back into the grid circuit by the tickler coil charges the variable condenser in the grid circuit, first on one side and then on the other, setting up local oscillations in the circuit consisting of this condenser and the secondary

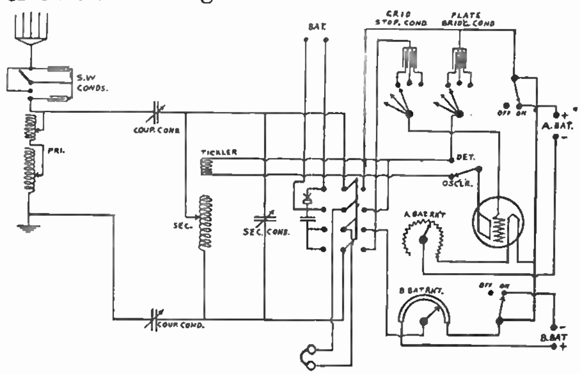


Fig. 278. De Forest Receiver Manufactured for the Government During the World War.

of the receiving transformer. By tuning this circuit so that it has a natural period slightly different from that of the incoming signals, reception is accomplished by the heterodyne method, and continuous-wave signals may be heard. As the note heard is due to the difference between the local oscillations and the frequency of the received signals, the pitch of this note is under the control of the operator. For damped-wave reception, interrupted waves and telephone broadcasting, oscillation of the tube is undesirable, as it will distort music and the voice. *Regeneration,* however, is useful and can be obtained by tuning to the point just preceding oscillation. Oscillation is recognizable by the characteristic whistling sound. This may be produced and then carefully tuned out. In this form of regeneration there is the effect of an apparent reduction of the resistance in the circuit, the effect upon the tube being such as to keep the circuit oscillating. This is sometimes called a *negative resistance.* If the polarity of the plate coil is not correct, the feed-back action will not take place, and connections to this coil must be reversed. It is possible to use a single antenna inductance with a tickler coil coupled to it. With a single-circuit regenerative receiver, the antenna-to-ground capacity replaces the variable condenser used in the secondary of an inductively coupled circuit. While the latter may require a little more tuning than the

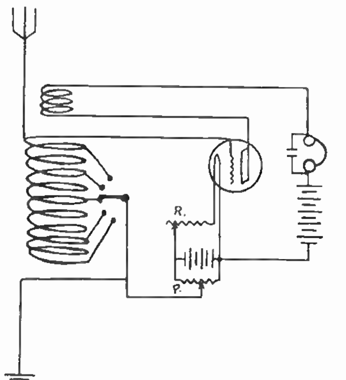


Fig. 279a. "Single-Circuit Regenerative Receiver.

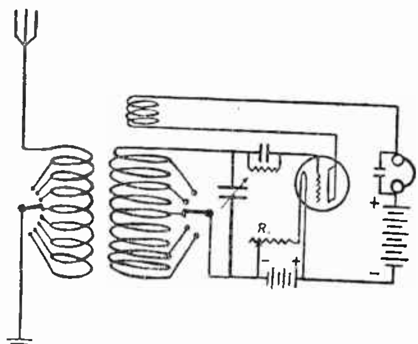


Fig. 279b. Fundamental Circuit of Inductively Coupled Regenerative Receiver.*

single-circuit type, it gives more satisfactory results when properly adjusted. The honey-comb coils shown in figure 276 are machine wound, flat and compact, and mounted so that they may be swung closer or farther apart on hinges. As the inductance of these coils is fixed, and no taps can be conveniently taken from them, it is necessary to employ a number of sets of coils for different wave lengths, plugging

*See paragraph 312, page 357, for construction data.

them into the hinged mounting as needed. When the grid condenser is not employed, it is an advantage to make the grid return connection to the A battery by means of a potentiometer shunted around that battery, as shown in figure 276, and tuning with this potentiometer is quite effective. When not in use, one contact to the filament battery should always be disconnected, to avoid unnecessary drain on it through the potentiometer, which, while a high resistance, is a short-circuit across the battery terminals. Sometimes

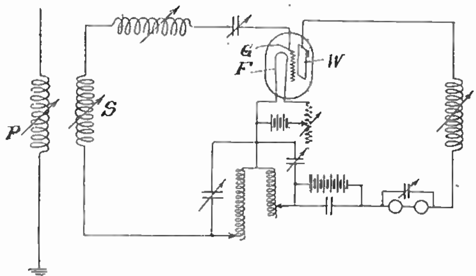


Fig. 280. Feed-Back Circuit from Armstrong, 1914, Patent.

a potentiometer is used as in figure 277, where it gives a control of plate voltage, which is both economical and convenient. This diagram contains an optional switching device with which the tickler coil may be cut entirely out of the circuit if desired. This is convenient in copying damped-wave telegraph signals, which usually sound better if this coil is eliminated. The tickler coil consists of a spiral winding either over a wooden ball or a piece of pasteboard tubing, and rotated inside of the secondary of the receiving transformer.

309. Regeneration may be produced by other arrangements than the tickler coil style of coupling between the grid and plate circuits. In figure 283 is shown a popular

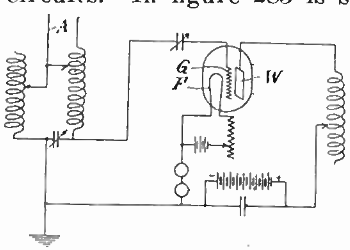


Fig. 281. Diagram from Armstrong Patent.

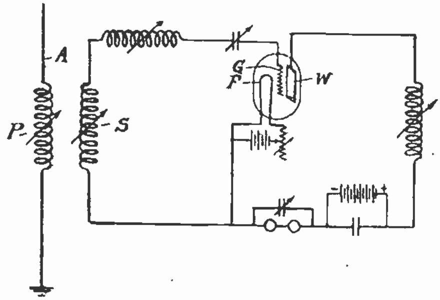


Fig. 282. Diagram from Armstrong Patent Showing Tuned Grid and Plate Circuit Without Inductive Coupling Between Them.

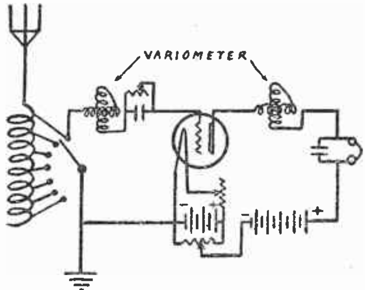


Fig. 283. Two-Variometer Regenerative Circuit.

two-variometer circuit. A variometer is constructed similar to a variocoupler except that no taps are taken from either coil, and the two coils are joined in series as indicated in the diagram. Varying the position of the movable coil changes the inductance in the circuit. In circuits of this type regeneration is accomplished through the capacity between the electrodes of the tube itself, due to the inductance in the plate circuit having an effect similar to reducing the resistance of the grid circuit, which changes the voltage of the grid, and keeps the oscillations repeating themselves.* It is possible to operate this circuit without the grid variometer if the secondary condenser is shunted across this part of the circuit.

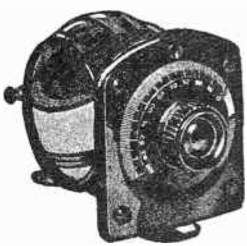


Fig. 284. Variometer. (Atwater Kent.)

*See *Scientific Paper of the Bureau of Standards No.* 351, *The Dependence of the Input Impedence of the Three-Electrode Vacuum Tube Upon the Load in the Plate Circuit*, by Dr. J. M. Miller (5 cents, at Government Printing Office, Washington, D. C.).

A somewhat different application of the regenerative idea is embodied in the Reinartz circuit. This is a small compact receiver adapted to amateur work and short wave lengths. One spider-web coil foundation about five inches in diameter is used for holding all of the inductance

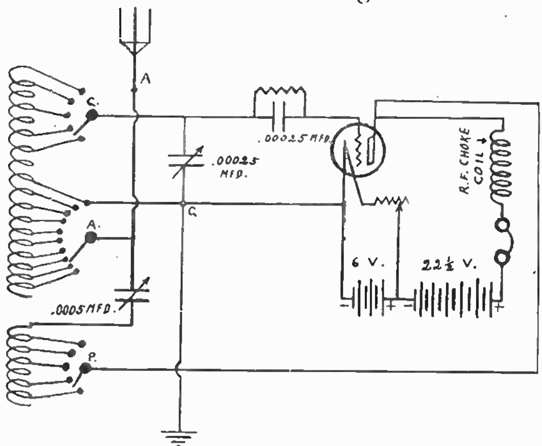


Fig. 285. Reinartz Receiving Circuit.

in the set. This is generally made with about forty turns of No. 26 silk-covered copper wire wound on the form near the center, as shown in figure 286, and used for the feed-back coil. Fifty turns are then wound, with taps

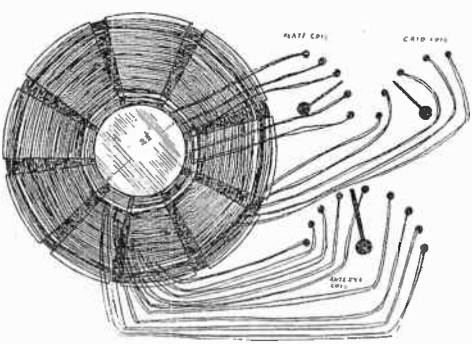


Fig. 286. Reinartz Coil.

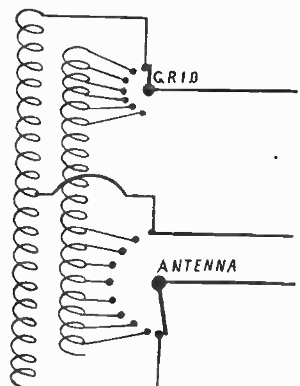


Fig. 287. Method of Employing External Inductance with Reinartz Receiver.

connected to the antenna switch. The outer portion of this coil, 40 turns, is connected to the grid. The condenser located in the plate circuit, for controlling the feed-back, has a capacity of about .0005 mfd. The method of connecting the secondary condenser to the ground is to reduce capacity effects due to the proximity of the operator's body. Adjusting the dials of a vacuum-tube receiver will frequently result in a "howl" from this cause. A radio-frequency choke coil consisting of 500 turns of No. 28 cotton-covered copper wire wound over a fiber tubing about 8 inches long and 2 inches in diameter is connected in the plate circuit to prevent oscillations produced in the grid circuit from passing back through the plate circuit. This is not always included. As described, the wave length of this set would be from 150 to 400 meters. If it is desired to receive on longer wave lengths, an appropriate amount of inductance may be obtained by eliminating the spider-web grid and antenna inductance and employing a separate coil externally as indicated in figure 287. Spider-web coils are often used for

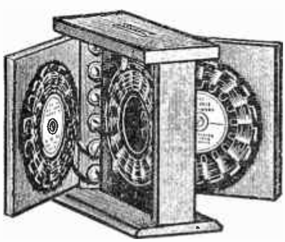


Fig. 288. Mounted Spider-Web Inductances for "Three-Circuit" Regenerative Receiver.

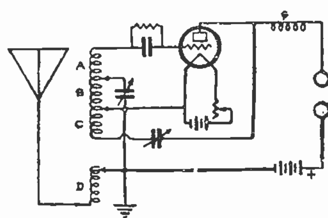


Fig. 289. Reinartz-Zenith Short-Wave Receiver.

small apparatus where their comparatively small amount of inductance is sufficient for what is needed. The Reinartz receiver may be made up with either standard tubes and storage battery, or with the small dry-cell tubes. The latter are preferred where portability is desired.

Figure 289 is the Reinartz-Zenith short-wave receiver. Coil A, B and C is divided into sections of the tuning inductance. This may be wound as shown in figure 286 on a frame about 3½ inches in diameter, or it may be a single-layer winding on a cylinder. For the 20-meter band, each section has only three turns. For the 40-meter band 6 turns are used, and 12 turns for 80 meters. Coil D is composed of five turns of No. 16 double cotton-covered wire for the band from 20 to 40 meters, and ten turns for 80 meters. Coil G consists of No. 30 d.c.c. wire wound over a form three inches long and one inch in diameter. The condensers have five plates each.

310. The famous *ultra audion* circuit, invented by De Forest, is shown in figure 290. In this the tube is caused to produce oscillations through the capacity in the tube.

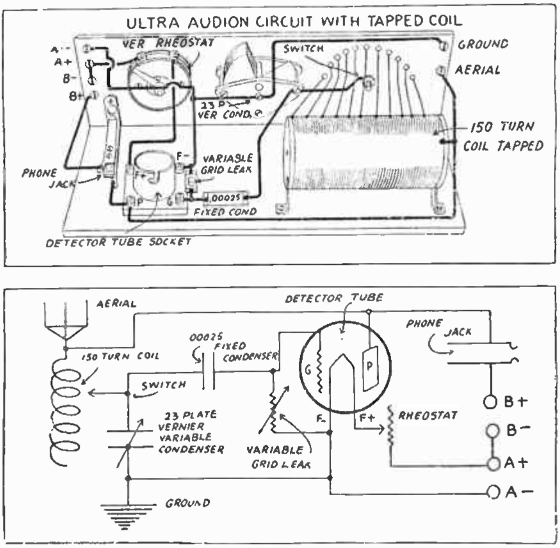


Fig. 290. Ultra Audion Circuit, Conductively Coupled.
(Courtesy Broadcast Receiver, SNL Tech. Syndicate.)

This circuit is popular with students who wish to copy the long-wave code transmission of the high-powered government and commercial stations. For this purpose a 1500-turn honey-comb coil is used with a 43-plate condenser. With the inductance and capacity as in figure 290 the broadcast band of wave lengths would be covered.

311. What can be done with a single vacuum tube for broadcast receiving is the subject of much space in current radio magazines, and new frills are continually being suggested, some of them to be forgotten immediately and others

to remain as permanent improvements. Only the fundamental circuits, with a small number of the popular adaptations, can be included here. Among the numerous circuits which have had wide popularity with amateur experimen-

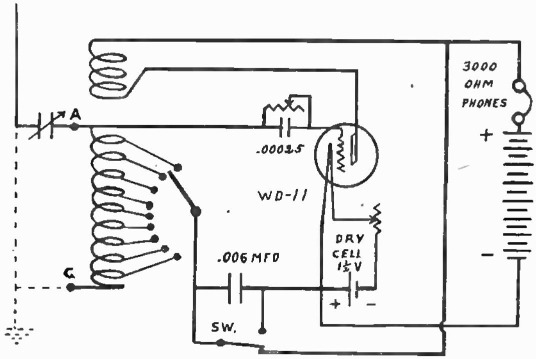


Fig. 291. Flewelling Receiving Circuit.

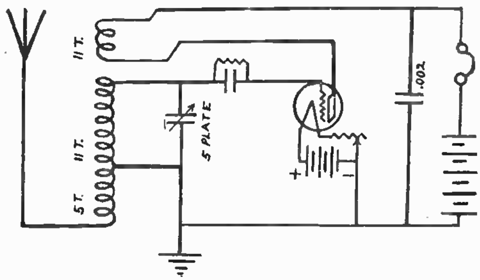


Fig. 292. An Amateur Short-Wave Receiving Circuit.

ters is the regenerative circuit developed by Mr. E. T. Flewelling and known as the Flewelling circuit. The first examples of this contained several .006-mfd. fixed condensers, but a later form is as shown in figure 291, where only one .006-mfd. condenser is used, and this may be short-circuited by a switch which makes the circuit perform as an ordinary tickler-coil feed-back. When the .006-mfd. condenser is thrown in the circuit, we have a form of super-regenerative action, which consists primarily of establishing a *control of the polarity of the resistance* in the circuit. When this is accomplished successfully, the amplification is *greatly increased.* Tuning is extremely critical, and body capacity effects when the operator's hand is placed near the dials pronounced. When the super-regenerative circuit is employed, this receiver will usually operate without an external antenna or ground, the coils serving to pick up sufficient energy for operation of the telephones. However, a connection to either aerial or ground decreases the tuning difficulties and increases the range. A hard tube is found to give best results as a detector in this circuit.

312. The coils in the circuit of figure 279b would, for the broadcast wave lengths, consist of about 20 turns of number 24 or 22 silk or cotton-covered copper wire for the primary, with about 45 turns of the same for the secondary and about 20 turns for the tickler coil. The diameter of the larger tubing is usually about 3½ inches. The primary and secondary may be constructed to vary their relation, as indicated in figure 175, or the taps on the secondary may be omitted and a variocoupler made, as in figure 200. Several popular makes of "three-circuit tuning coils" are on the market, in which the primary and secondary are stationary, being wound on opposite ends of the same tubing. When wound end to end in this manner the coils are wound in the same direction. If placed one inside of the other they should be wound in opposite directions in order to obtain magnetic induction between them. The tickler coil is usually mounted on a shaft that permits it to be rotated within the secondary coil.

A serious difficulty encountered in the operation of one-tube regenerative circuits is that the oscillations set up in the receiving set are radiated from the receiving antenna. In other words, the apparatus is acting as a low-powered transmitter of the oscillations. These may be picked up by a neighbor who is listening in, and produce a loud whistle in his receiving telephones which it is difficult for him to tune out. It is possible to handle these receivers in such a way that they do not radiate. They must be tuned down from the oscillating point, so that they do not whistle. This requires experience with the set, to learn its particular characteristics. In thinly settled districts, where neighbors are not likely to be annoyed by its radiation, the single circuit receiver is quite satisfactory. However, by adding one or more stages of radio-frequency amplification the distance range of the apparatus may be increased, and the oscillations produced by regeneration prevented from reaching the antenna. One stage or more of audio-frequency amplification will also greatly increase the volume of the signals.

CHAPTER 34

Vacuum-Tube Transmitters

Simple Vacuum-Tube Transmitter — Various Transmitting Tubes — Hartley, Colpitts and Meissner Circuits—Low-Resistance Ground—Counterpoise—Master Oscillator—Keying—Motor-Generators for Tube Sets—Dynamotor—A. C. Supply—A. C. Modulation—Magnetic Method of Modulation—Spark-Coil Tube Transmitter—Rectifiers for A. C. Plate Supply—Home-Made Transformer — Transformer Specifications — Heising Tone Transmitter — Bouchardson Three-Phase Self-Rectifying Transmitter—Three-Phase Kenotron System—Mercury-Arc Rectifying System—Airplane 100-Meter Transmitter and Tests for Directional Effects—Bank-Wound Inductance—Table of Inductance for Coils of Various Diameter—Choke Coil—Quartz Crystal —General Letter to Amateurs—Short-Wave Amateur Station—De Forest Short-Wave Tube—Characteristics of Short-Wave Transmission—Polarized Waves—U. S. Signal Corps Short-Wave Station—Short-Wave Transmitting Antennæ—Byrd and Wilkins Polar Expedition Short-Wave Transmitters—Table of Popular Short-Wave Stations of the World—Brass-Pipe Condenser—Compressed-Air Condenser—Stations 5WS, 3TD, 3BKC, 1XAU, WVB, WVA, WVX, WVC, NAA, NSS, KEGK, LPZ.

313. The discovery of regenerative circuits for receiving led to the application of this principle to the generation of continuous oscillations for transmitting. It is possible to ob-

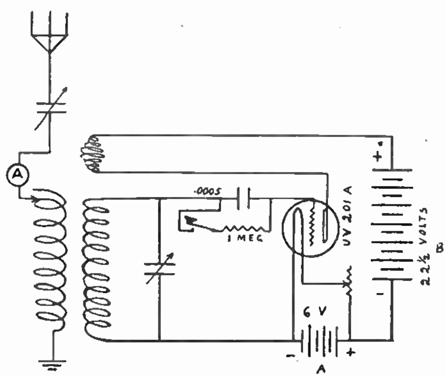


Fig. 293. Simple Tickler-Coil Transmitter.

tain, by the use of vacuum tubes, current of any desired frequency, and the radiated waves will be pure and sharp, and the tone at the receiving station high-pitched and clear. A simple tickler-coil receiving set may be converted into a low-powered transmitter by removing the receiving telephones from the plate circuit and inserting a key in series with the grid leak, as shown in figure 293, or the key may be placed in series in the filament circuit. Closing the key starts the first movement of the plate current, and the feed-back action keeps the variations going, so that oscillations are produced

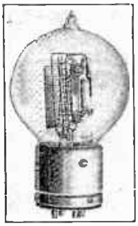


Fig. 294. Western Electric 5-Watt Transmitting Tube.

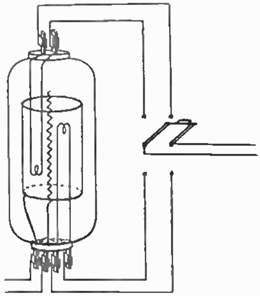


Fig. 295. Murray Double-Filament Power Tube.

in the grid circuit. In receiving, these oscillations are superimposed upon the received signals to produce a beat note. Here we use the oscillations alone. The fact that these oscillations can actually be used, even in a low powered piece of apparatus like that indicated in figure 293, for the purpose of transmitting signals which may be intercepted by a nearby receiving station, is further proof of the interference that may be caused when a receiving set is allowed to radiate its locally produced oscillations.

314. The development of vacuum-tube transmitters has been associated closely with the development of aeroplanes, where a high percentage of efficiency in proportion to the bulk of the apparatus is important. Outside of the Government work in connection with aeroplanes, it has been peculiarly linked with the activities of the better class of amateur stations, the patent situation in the United States having been such that for several years the tubes were not available for commercial work in transmitting paid messages. Immediately after the possibilities of transmitting telegraph signals by the use of vacuum tubes was realized, there was a sudden development in varieties of tubes suited

for higher power than that which had been used for receiving apparatus, and in varieties of oscillating circuits. These circuits, by process of elimination, have gradually sifted down to a comparatively small number of more or less standardized circuits, generally given the names of their inventors.

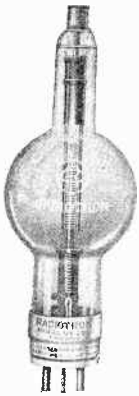


Fig. 297. 250-Watt Radiotron, UV-204.

Fig. 296. 50-Watt Radiotron, UV-203.

315. The appearance of the higher powered tubes now in general use for transmitting is quite different from the receiving tubes, but the fundamental principle of their operation is the same. As the size of the electrodes is increased the capacity for power is increased accordingly, and the more nearly evacuated is the tube, the higher plate voltage can it stand. The 5-watt tubes are suited for low-powered aeroplane or amateur apparatus. Two 5-watt tubes in parallel will give about 1.5 amperes in the antenna circuit, and give a transmitting range of about 200 miles. The filaments of these tubes are operated on 7.5 volts and 2.35 amperes, and the plates at a voltage of 350 with about .05 ampere. The 50-watt radiotron is operated with 10 volts and 6.5 amperes on the filament with 1,000 volts and .15 ampere on the plate. One 50-watt tube will give about 2.5 to 3 amperes antenna current and give a transmitting range of about 1,000 miles. The 250-watt radiotron is constructed with a special filament for extending the life of the tube. This type of tube is used by the Radio Corporation of America in its high powered official broadcasting stations. It is operated with 11 volts and 14.75 amperes filament current, and .25 ampere plate current at 2,000 volts.

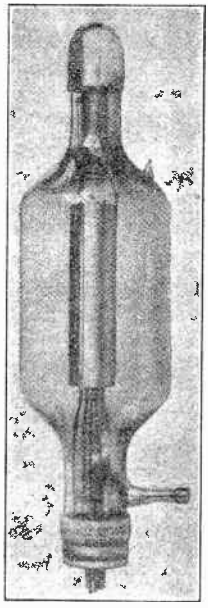


Fig. 298. A 3-K. W. Air-Cooled Tube.

316. Power tubes are rated for their *power output.* About

one-half of the power delivered to the plate of a transmitting tube is wasted in heat, considerable difficulty having been experienced with this high plate temperature. Principally on account of this, it has become the custom to connect two or more tubes in parallel to procure the desired power, instead of using a single higher powered tube for this purpose. Plates have been given different shapes with the idea of providing the best obtainable radiation of heat, so as to get rid of it as soon as possible. Extensive experiments in plate-cooling systems were conducted at the U. S. Navy Yard in Washington. The General Electric Company manufactures a water-cooled tube, known as the UV-207. In this the plate forms a cylindrical shell comprising the lower half of the tube. The tube is mounted in a supporting rack, and water is circulated through the plate, in a manner somewhat similar to the water-cooling system employed with the arc transmitter. In earlier types the lower portion of the tube was immersed in a receptacle containing running water. The filament is tungsten, and much heavier than those formerly used in vacuum tubes. The grid consists of a cylinder around the filament. The water cooling makes possible the use of a smaller plate surface area than could otherwise be used, and thus reduces the space-charge within the tube, increasing its efficiency. The filament of the 20-K. W. water-cooled tube draws 50 amperes and is operated at 20 volts. The plate voltage is about 15,000. A 100-K. W. tube of this type is made, being about 2 feet high and drawing 91 amperes on the filament.

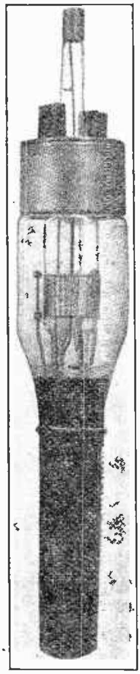


Fig. 299a. Water-Cooled Transmitting Tube, Radiotron UV-207.

Helium gas, with no other gas mixed with it, has proved successful in encouraging the electron flow in a transmitting tube without increasing its heat. According to F. S. McCullough, in an article in QST, of November, 1924, "Seventeen of the largest broadcasting stations use these tubes each evening. These are the first stations in the world to use the helium atom as a carrier of radio-frequency currents."

317. A new type of double-filament tube has been patented by Sergeant Charles Murray of the U. S. Signal Corps. The

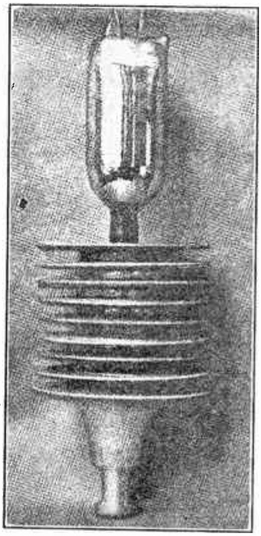


Fig. 299b. An Air Cooled Helium Tube. (QST.)

tubes are made with flat contacts similar to switch blades and clips. The lower blades were originally used for the electrical connections to the electrodes, and the upper blades were solely mechanical. The invention consists of adding an extra filament to be connected to the upper contacts, the electrodes being so arranged within the tube that the capacity between them will be the same with either filament in use. Connections are made to the clips by means of a switch as indicated, and either filament may be used as desired. This makes possible a change from one to the other during long service, as well as providing means for continuing work in case one of the filaments burns out. As the rated life of a 3-K. W. tube is only about 400 hours, and the life of others in proportion, and the price of one tube is several hundred dollars, the value of any such economical device is appreciable.

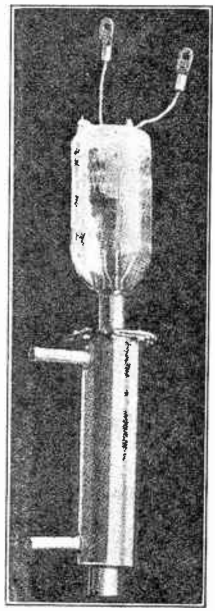


Fig. 299c. The Helium Transmitting Tube with a Water Cooling System. (QST.)

318. The actual power output of the tube itself cannot equal the power input of the plate, an allowance always being made for plate power dissipated in heat. However, on account of the antenna circuit having a resistance many times less than the internal resistance of the tube, it is possible to have the antenna ammeter indicate a *current* greater than that originally supplied to the plate of the tube.

Vacuum-tube transmitters contrasting with spark and are transmitters which are rated for power input, are rated for *power output.* The tube acting as a rectifier of the oscillating current, reduces it to a one-way pulsating current, utilizing only one-half of the input. This 50 per cent. loss of power, with the added heat losses, brings the total efficiency, power output to power input, down to about 25 or 30 per cent.

319. With any circuit which provides a feed-back, either through a magnetic or capacity coupling, once any slight variation has been caused in the voltage of the grid, this will be reflected in the output of the source of power supplied to the plate, and this variation in plate current will cause another variation in grid voltage, which causes a corresponding variation in plate current, etc.; and the circuit continues to oscillate at a period determined by its inductance and capacity. *The changes in grid voltage must be of sufficient amplitude to keep up the variations in the plate current with sufficient volume to provide the feed-back power to maintain the oscillations.* The original disturbance in the grid potential may be produced in a number of ways. Any disturbance in the steadiness of the plate current, which is under control, will vary the grid potential and cause the tube to generate oscillating current.*

Figure 301 illustrates the Hartley circuit. This is based on an autotransformer feed-back action, accomplished through a single coil located in the antenna. The circuit was used extensively in the first radiotelephone stations of the Radio Corporation of America. The original circuit was conductively coupled to the antenna, but this feature of it is obsolete now. The inductively coupled Hartley is popular with amateurs, and is used considerably in the U. S. Navy. In this illustration a small high-potential d. c. generator is indicated instead of the plate battery. The 1-mfd. condenser is used as a protection to the generator windings, and the choke coils in the generator output lines are

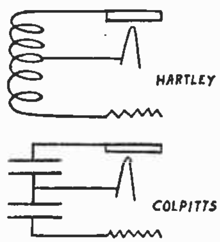


Fig. 300. Theoretical Hartley and Colpitts Circuits.

*For an exhaustive scientific treatment of the performance of vacuum-tube oscillators, see *Proceedings of Institute of Radio Engineers,* June, 1923, page 275, article by D. C. Prince.

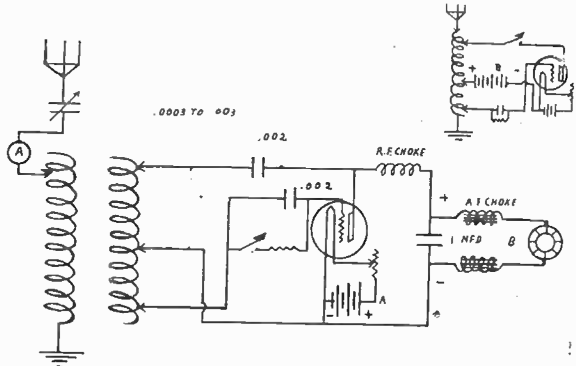


Fig. 301. Fundamental Hartley Transmitting Circuit.

employed to "smooth out commutator ripples." If low power is used, say one tube of an output of 5 watts, the hand key may be connected in series in the plate circuit, but for greater power it is necessary to use a magnetic relay if the keying is done in the plate circuit, on account of arcing. Connecting the key in the grid often causes a recognizable "spitting" noise, which is eliminated if the break and make is made in the plate circuit. Figure 302 shows the Colpitts arrangement. This is essentially a capacity-coupled system.

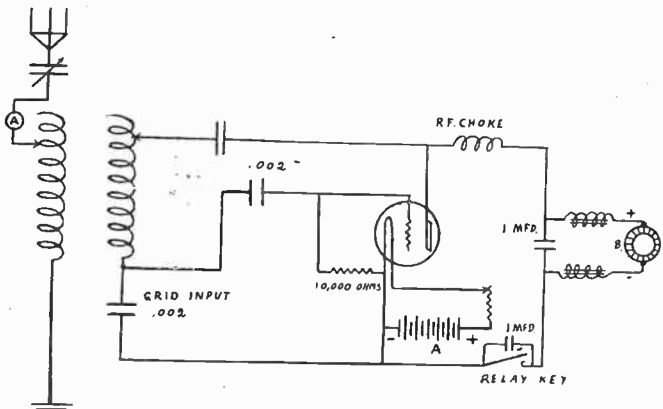


Fig. 302. Fundamental Colpitts Circuit.

The oscillating circuit is composed of the grid condenser, grid-input condenser, and the grid leak, which must be so connected as to form a path back to the filament as shown, or the circuit will not function. The grid feed-back takes place through the capacity between the electrodes inside the tube. Figure 493, paragraph 409, illustrates a modern ship installation employing the Colpitts system of generating oscillations.

The Meissner circuit, shown in figure 303, is easier to manipulate than those illustrated in figures 301 and 302, and gives a somewhat smoother voltage regulation. This circuit was developed by Dr. Meissner of the Berlin Telefunken Company. The Hartley and Colpitts were each worked out by engineers of the General Electric Company.

The tuned plate and grid circuit, shown for receiving in figures 282 and 283, is also used for transmitting, and has proved especially successful on extremely short-wave lengths. This arrangement was employed for the short-wave transmitter taken on the Byrd Arctic Expedition, illustrated in figures 338c and 338d.

When the plate supply is connected in parallel it is customary to connect a radio-frequency choke coil of from one to three millihenries in series with the source of power, to

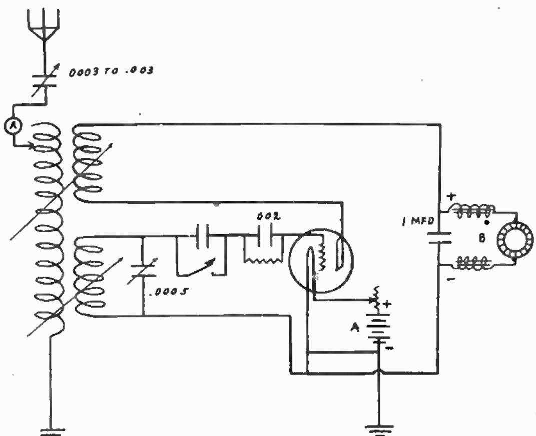


Fig. 303. Fundamental Principle of the Meissner Circuit.

prevent any back-rush of the radio-frequency, and a blocking condenser between the plate and the plate coil to prevent short-circuiting the d. c. plate supply.

320. The design of the antenna system for a transmitting station is always important. The ground should be carefully selected with a view to obtaining minimum resistance. Quoting from *Radio Telephony for Amateurs* by Stuart Ballantine, "All of the energy supplied by the power source to the antenna is *not radiated by it. The efficiency of an antenna system as a radiator may be taken as the ratio of the power radiated to the power supplied* and the object of antenna design is to secure a system in which this ratio is as large as possible. The most prolific source of loss in antenna systems, especially at short wave lengths, is the heat generated in the earth by currents returning to or coming from the lead-in. Remembering that the heat loss is equal to $I^2 R$, it is clear that the loss in any unit cube of the earth material goes up as the square of the current density at that point; consequently in order to keep down the whole loss the *point* is to be avoided. The distribution of current depends upon the wave length, conductivity and dielectric constant of the earth, as well as upon the geometry of the antenna. A symmetrical antenna will give a better distribution and consequently a lower earth resistance than one which is not symmetrical. The current flows by a conduc-

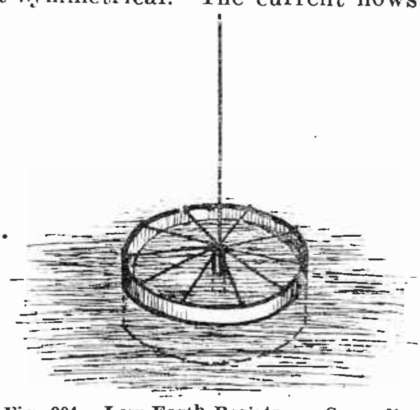


Fig. 304. Low-Earth-Resistance Grounding.

tive path up through the antenna conductors, thence by capacity paths to the earth, and finally through the earth to the lead-in. It is precisely the concentration here that causes most of the loss in the average grounding system. The loss may be diminished by reducing the current concentration, and this may be accomplished by providing a generous surface in the grounding electrode." An early type of grounding, devised in Germany, was proved by Mr. Ballantine to offer a low earth resistance. It consists of sheets of galvanized iron buried edgeways in the earth to a depth of about three feet, and arranged in a circle about 15 feet in diameter. The ground wire from the antenna is then attached to a wooden post, and several wires taken from this out to different points on the iron circle. The strips should be soldered together.

321. A *counterpoise* is a more convenient method of overcoming the concentration of earth current at the base of the antenna, also it is usually less expensive. The counterpoise generally consists of a network of wires arranged *directly beneath the antenna,* and as near the earth as can be conveniently arranged, but *not grounded at any point.* It should always be sufficiently large to lie between the antenna and the ground in such a way that the antenna does not protrude beyond it at any spot. It may be larger than the antenna without harm, but its effectiveness is decreased if it is smaller. A tin roof is sometimes successfully employed for a counterpoise, provided it is not grounded by rain spouts, wires, or other possible conductors. This is often convenient in the city where ground space is valuable. The poles supporting the counterpoise, if it is erected directly over the earth, should be carefully insulated, or better still, made of insulating material, such as porcelain or glass. In some cases, the counterpoise is built completely around a radio shack, where the shape of the antenna requires this, but it is better to have nothing but the air between the antenna and the counterpoise. The action of the counterpoise over the earth is exactly the same as a condenser; in fact, it *is* a large *condenser,* conforming to all of the laws pertaining to condensers. If no ground connection is made from some other portion of the apparatus, the only connection between the transmitter and the earth is electrostatic.

322. Each of the transmitting circuits shown above may be called a self-exciting circuit, that is, oscillations are produced by some form of regenerative coupling of the circuit. An arangement for obtaining high-frequency high-voltage

alternating current which is having wide application, especially in radiotelephony, is known as the *master-oscillator* system. In this an oscillator circuit is coupled to a non-regenerative circuit which may consist of one tube, or several in parallel, and which is used merely as an *amplifier*

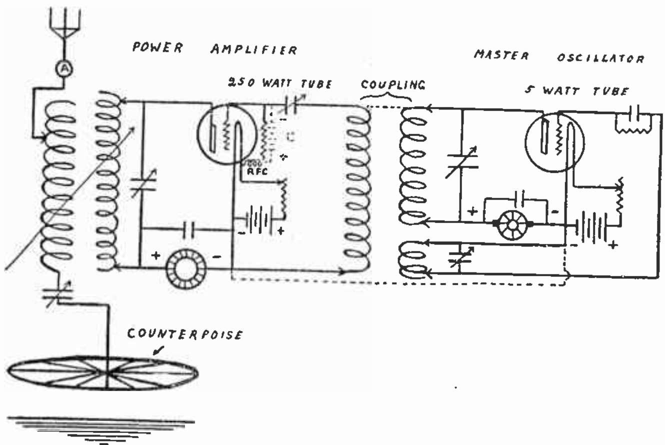


Fig. 305. Fundamental Arrangement of Master-Oscillator System.

of the energy of the oscillations delivered to it from the lower powered master oscillator. This is due to the amplification factor of the tubes as they draw current from the plate supply, adding this energy to the output of the apparatus. Endless combinations are possible with this method. Compared to the previous circuits this is known as a *separately excited oscillator*, that is, the power-amplifying circuit is oscillating, but not by self-generated oscillation. It oscillates under the influence of the master oscillator. Figure 305, for simplicity, shows the fundamental arrangement with inductive coupling between oscillator and amplifier. However, it has been found that with this there is difficulty due to "wild" oscillations produced in the amplifier by the inductance coil in the grid circuit. Capacity coupling overcomes this trouble. Dotted lines indicate connections for this. Tubes may be operated, with proper means of control, from the same supply. The master-oscillator system has the advantage of separating the oscillator from the antenna circuit, with the result that the frequency of the oscillator is not affected by any slight changes in antenna capacity, such as might be caused by its swinging in the wind; and the wave length is therefore more nearly uniform. The antenna and local oscillator are tuned to the same wave length.

Figures 503a and 503b, paragraph 516, are photograph and diagram of a 2-K. W. master-oscillator apparatus designed by the General Electric Co. for the U. S. Coast Guard.

323. In the majority of tube transmitters where considerable power is desired, two or more tubes are connected in

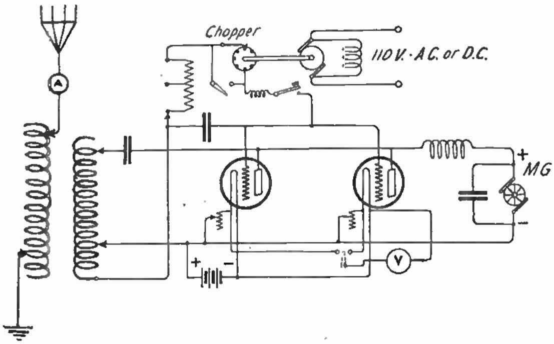


Fig. 306. Hartley Transmitter with Tubes in Parallel and a Chopper for Sending Interrupted Continuous Waves.

parallel. The tubes act like resistances in parallel, that is, the internal resistance of the parallel tubes complies with Ohm's law for other parallel resistances, reducing the joint resistance of the group and dividing the current. This makes it possible to increase the power output of the apparatus by the use of low-powered tubes in parallel, reduces the trouble due to hot plates, and is usually more economical than the use of one high-powered tube. This has, of course, its limitations, as there is a point where, other things being equal, the resistance falls too low to be practicable. Also, if the tubes have even slightly different characteristics, undesired oscillations may be produced. In figure 306 the key is located in series with the grid resistance, and a convenient arrangement is indicated whereby a chopper may be utilized for sending interrupted continuous waves for crystal- detector reception. The principle of this is the same as previously mentioned in connection with the arc transmitter. The small reactance coil in series with the grid resistance is often used when tubes are connected in parallel, for the purpose of smoothing out disturbances caused by "wild" oscillations. The sound of the chopper-interrupted tube transmitter is easily recognized after a little experience in copying it. While of comparatively low pitch, it is much more musical than the note of the spark transmitter.

324. Motor-generators are constructed especially for use in vacuum-tube transmitting apparatus. Their peculiarities are high voltage and small current, with a large number of commutator segments to reduce as much as possible the

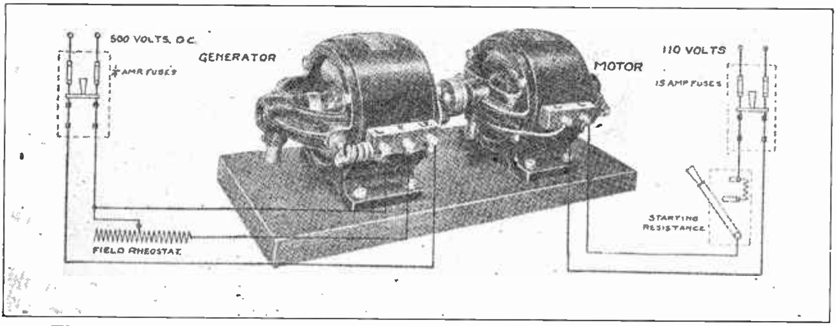


Fig. 307. 100-Watt 500-Volt Motor-Generator Designed for Tube Transmitters. Current 0.3 Ampere.
(International Radio Telegraph Company.)

rippling sound produced by the commutator. Figure 307 illustrates a special motor-generator with wiring diagram. This is a self-excited compound-wound generator, with a rheostat in series with the shunt field, the connections being similar to those indicated in figure 71, paragraph 118. The manufacturer offers an 8,000-ohm resistance for use with this machine. The motor may be a 110-volt shunt-wound d. c., or a 110-volt 60-cycle single-phase induction machine. Figure 308 illustrates a double-commutator generator, manufactured by the Electric Specialty Company. This contains two armature windings on the same frame, from which two separate voltages are obtainable, one suitable for the plates and the other for the filaments of transmitting tubes. Figure 309 is a four-unit set offered by the same company. This consists of a 10-horsepower three-phase motor, driving three generators, the four units being mounted on the same base and all connected by flexible couplings. Two of the generators deliver 1,000 volts, 2 amperes each, and are connected in series to obtain 2,000 volts, 4,000 watts. The third gen-

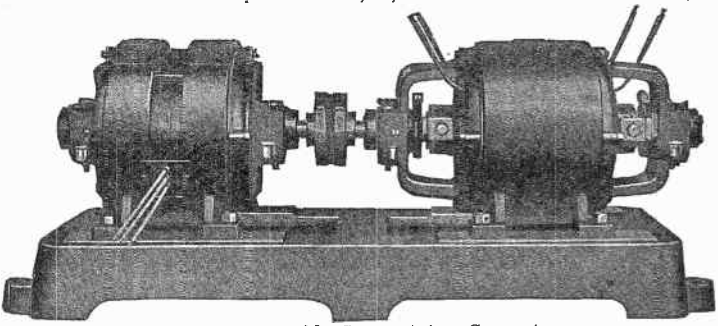


Fig. 308. Double-Commutator Generator.

erator delivers 1,800 watts at 12 volts. The high voltage is, of course, used for the plates and the low voltage for the filament lighting. The shunt fields of all three generators

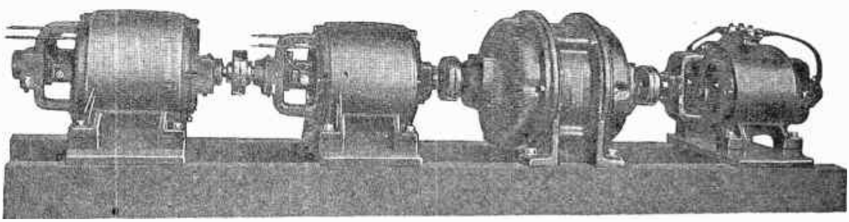


Fig. 309. Four-Unit Motor-Generator Set.

are excited from the 12-volt generator. The series field windings of the high-voltage generators are connected in series with the high-voltage line, and the series field of the low-voltage generator is connected with the low-voltage filament-supply line. For low-powered sets a dynamotor is often used for plate supply (see paragraph 155). If 5-watt tubes are used the plate supply should be about 350 volts. One or two tubes will require a 100-watt generator. If three or four tubes are used, they will call for a 200-watt generator. If 50-watt tubes are used, with 1,000 volts on the plate, a 200-watt generator is sufficient for one tube, or a 500-watt generator should be used for from two to four tubes. Carefully designed filters, consisting of choke coils and condensers, must be used with these machines to avoid

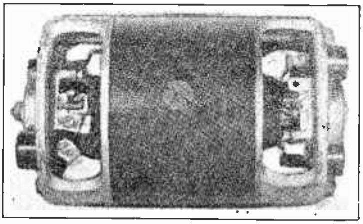


Fig. 310. 350-Volt Dynamotor to be Operated on a 12-Volt Storage-Battery Supply.

having the commutator ripple heard in the receiving telephones.

325. Alternating current, with a step-up transformer, is sometimes used for the plate supply of high powered transmitting tubes. The filaments are then lighted from a step-

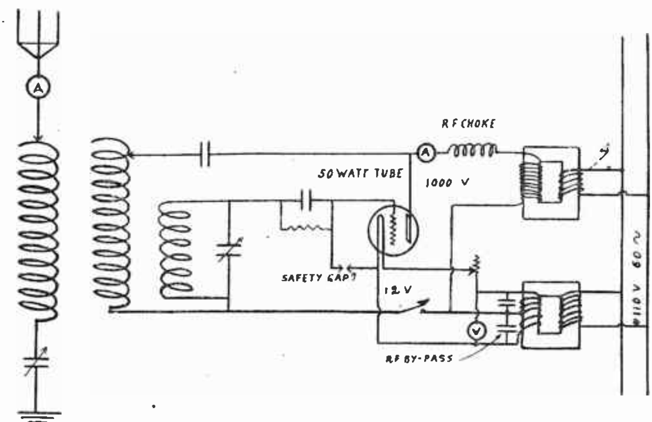


Fig. 311. Low-Powered Tube Transmitter with A. C. Supply.

down transformer operating on the same source. Alternating current is also often used by amateurs for low-powered transmitters, as it is generally found much cheaper to install the transformer than the d. c. motor-generator. The same *effective* value of alternating current is used as would correspond to the equivalent d. c. The use of alternating current on the filaments of power tubes prolongs their life considerably. The reversing current relieves the one-way wear on the filament caused by the direct current filament and plate supply, the combined effect of which may be to cause one side of the filament to carry more current than the other. There are two possible ways of utilizing alternating current for plate power, first to put it directly on the plate, using the oscillator tubes as both oscillators and

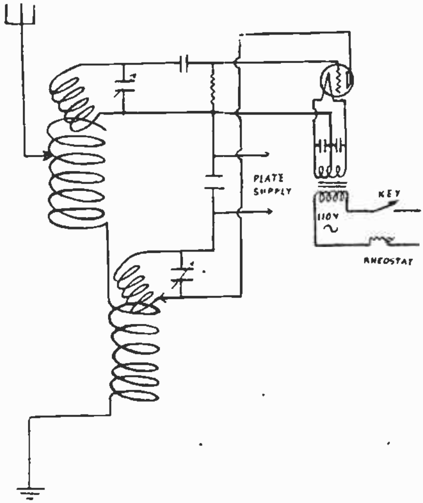


Fig. 312. Four-Coil Meissner Circuit with A. C. Supply.

rectifiers, and second to rectify the current with electrolytic or two-element valve rectifiers. When the alternating current is put directly on the plate, the apparatus is said to be a *tone* transmitter. There is an *audible*-frequency variation in the output, and the signals can be heard on a crystal detector. Likewise it may cause interference. As the tube itself is a rectifier, this is a *self-rectifying* circuit. When only one tube is employed, as shown in figure 311, the radiated waves will be in the form indicated in figure 313. As only one-half of the alternating supply can pass through the tube, the other half is completely cut off. The continuous oscillations generated by the feed-back part of the system are *moulded,* or *modulated,* under the influence of the alternations which do pass through. They are then radiated in audio-frequency groups of radio-frequency oscillations. This, it will be recalled, is what takes place with the spark transmitter; but in this case there is no natural damping as with the spark set, the rising and falling volume of the oscillations being timed with the rise and fall of each alternation of the alternating-current power supply. The pitch heard in the receiving station is determined by the frequency of the alternating current, hence the higher this frequency the better will the signals sound and the easier will it be to copy through interference. In figure 311, the key is shown in the negative filament line, and indicated in

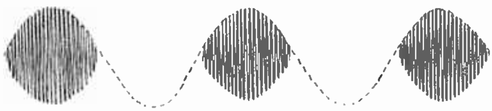


Fig. 313. Continuous Wave Modulated by a Half-Wave Self-Rectifying Transmitting Circuit.

dotted lines as in the primary of the plate transformer. The location of the key is usually somewhat of a compromise. Placed in the negative filament lead, it has been found to give a slightly greater antenna current, as a rule, than when in the primary of the transformer. However, when the key is in the primary of either the plate or filament transformer, the click, or "key thump," is reduced, lengthening the life of the tube and cutting down interference. The latter method does not prove successful where chemical rectifiers are used. The oscillating circuit shown in figure 311 is known as the "grid - tickler - coil circuit," the British -Aircraft circuit," and also as the "1DH circuit." It was made famous by station 1DH and by use on British airplanes. The circuit

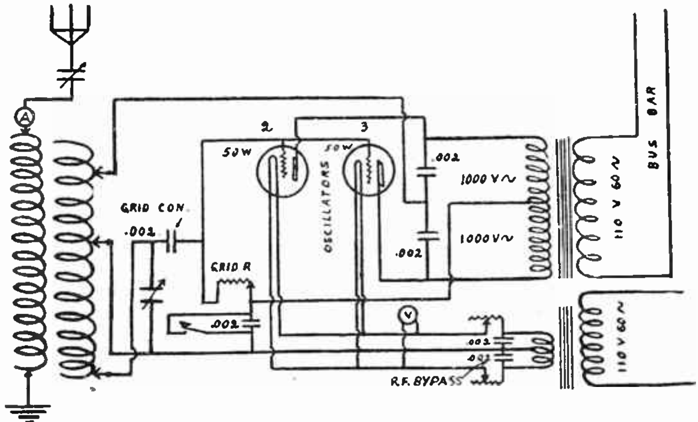


Fig. 314. Diagram of Full-Wave Self-Rectifying Transmitter.

shown in figure 312 is more recent in development than the other circuits shown in the accompanying diagrams, and it is finding favor in various modified forms in radiotelephony, as well as for telegraphy. It proves more convenient to handle than the three-coil Meissner. Details of an amateur station employing this circuit may be found in the July (1924) issue of QST.

If two tubes are connected with their plates at opposite ends of the secondary of the transformer, as in figure 314, each half of the alternating current will be used. This is called full-wave rectification. When one plate is positive the other one is negative, so that the alternations pass through the tubes alternately, the resultant output being in one direction. As there are twice as many clicks in the receiving telephones when the modulation is as shown in figure 315 as when it is as indicated in figure 313, it can be seen that the pitch of the signals radiated by a circuit using full-wave rectification will be higher than one using only one-half of the alternating current supply.

The tubes in figure 314 are numbered 2 and 3, and the cur-

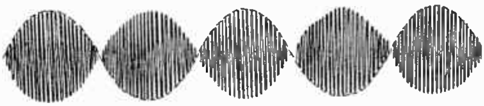


Fig. 315. Modulation Produced by Rectifying Both Waves of an Alternating-Current Power Supply.

rent rectified by them is indicated at 2 and 3 in figure 316. It can be seen that the final current is decidedly pulsating in character, as at 4, figure 316. The radio-frequency oscil-

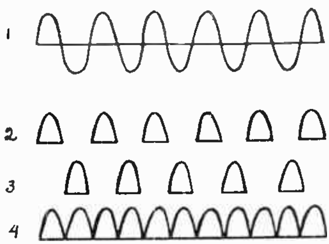


Fig. 316. Development of Full-Wave Rectification.

lations then rise and fall in amplitude in each direction, timed with the rising and falling amplitude of both alternations of the low-frequency power supply.

326. If the a. c. modulation is not desired, it is better to use separate rectifiers. Several types of rectifiers are in use for this purpose. The electrolytic rectifier, occasionally called an electrolytic condenser, consists of an arrangement having somewhat the appearance of a chemical cell. Chemicals used for the electrolytic rectifier differ with different makes. A saturated solution of ordinary borax, such as is used for cleansing purposes is usually employed. Ammonium phosphate is sometimes used and gives good results. Chemically pure water is used. The electrodes consist of a strip of lead and some other substance, usually aluminum. These must be "formed" by subjecting them to five or six hours of use in series with two or three lamps from the 110-volt line. When current flows through a cell a coating of gray hydroxide of aluminum forms on the aluminum plate and the lead plate turns a reddish brown. After this, the current flows easily from the aluminum positive to the lead negative inside of the cell, and from negative to positive in the external circuit, but cannot flow in the opposite direction. There is, however, a limitation to the voltage which a chemical rectifier will refuse to pass in the opposite direction. For this

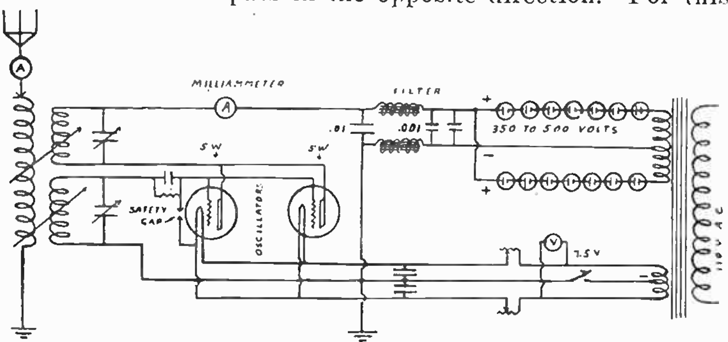


Fig. 317. Tube Transmitter Equipped with Chemical Rectifiers.

reason, several cells are generally used in series. These are mounted in wooden trays, and made as secure from spilling as possible. About one-fourth of an inch of a light grade of oil is poured on top of the electrolyte to prevent evaporation. The jars must be large enough to allow sufficient electrolyte to be used to radiate the heat generated within the cell, as heat reduces its resistance. Electrolytic rectifiers may be purchased ready made, but many experimenters find it worth while to make them. Glass fruit jars make convenient receptacles for the rectifying materials when fitted with bakelite or hard rubber tops. The electrodes should be of a size to allow at least one square inch for every 40 milliamperes of plate current to be used; and there should be at least one jar for every 50 volts. In some cases, where the jars are too small in size, or insufficient in number, the aluminum electrodes will become so heated as to give the appearance of a light in the jars. With separate rectifiers, and appropriate filtering systems consisting of choke coils and condensers which smooth out most of the ripple in the pulsating current supplied by the rectifiers, the modulating effect of the alternating current upon the radiated waves is diminished. At its best, it may be practically eliminated.

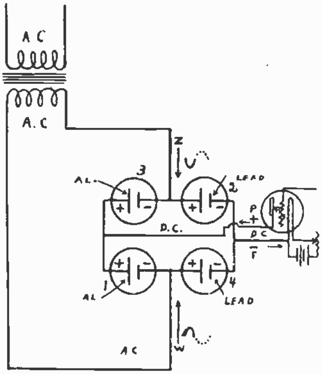


Fig. 318a. Chemical Cell Full-Wave Rectification.

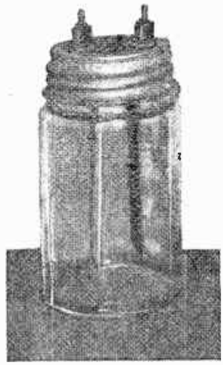


Fig. 318b. A Home-Made Chemical Rectifier.

This then provides the type of signals which require a regenerative circuit, or other local heterodyne or interrupting device at the receiving station, in order to be heard, and which are not audible on a simple crystal-detector receiving set.

The full-wave rectification may be made somewhat clearer by considering the circuit given in figure 318a. It can be seen that with the tube connected in parallel with the rectifiers, as shown, the separate alternations will all pass through the tube in one direction, the path of the current passing in the direction indicated as W will be through cell 4, from filament to plate in the tube, through cell 3, and into the external circuit. Current passing in the direction indicated as Z passes through cell 2, the tube, and cell 1. If this is traced, it can be seen how each half of the alternating current is used.

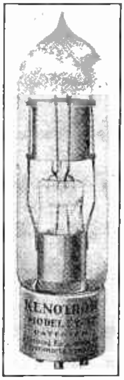


Fig. 319. Kenotron UV-217.

327. In some installations a mechanical rectifier, such as illustrated in figure 86, is used. This consists of a synchronous commutator-like device revolved by a synchronous motor. The number of segments required is determined by the frequency of the current to be rectified and the speed of the motor. To determine this, divide the frequency of the current in cycles per second by the revolutions *per second* of the motor, and multiply this by two. One segment is required for each alternation.

For higher voltages than that for which the mechanical and chemical rectifiers are suited, two-element vacuum tubes are employed almost exclusively. Among the best known of these rectifier tubes are the Kenotrons. They come in sizes and capacities appropriate for power tubes of corresponding ratings, and have much the same general appearance as the power tubes, except that the grid is lacking. The Kenotron UV-217 is intended for use with 50-watt tubes, the UV-216 for 5-watt tubes, and others for higher power. These rectifying tubes have their filaments lighted from the same alternating-current-supply which they are ulitized to rectify. One rectifier tube is used for each power tube, and these are connected for full-wave rectification. Figures 321 and 322a are amateur transmitting circuits using kenotron rectified plate supply.

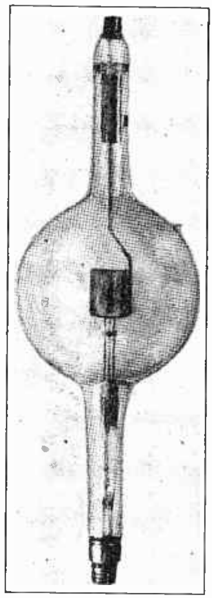


Fig. 320. Kenotron for High-Powered Transmitter.

Figure 322a is the transmitting system used by 5WS, the station of the Radio Society of Great Britain, which is interesting on account of its having been constructed for the specific purpose of reaching America with its signals, and having accomplished that purpose. The following data concerning this station is extracted from QST, June, 1923: The antenna was a six-wire cage, 94 feet long, arranged nearly vertical, with the upper end about 200 feet from the ground. The

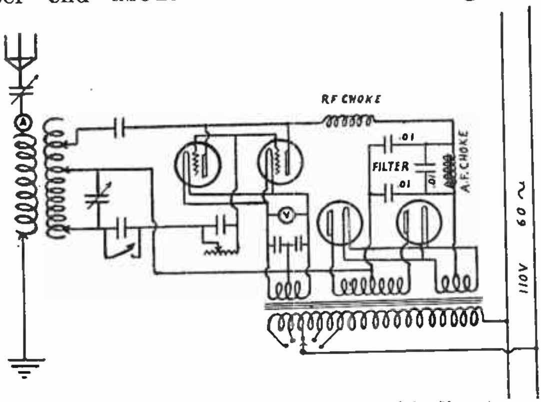


Fig. 321. Vacuum-Tube Transmitter Equipped with Kenotrons for Full-Wave Rectification.

spreaders were bamboo, and made the cage six feet six inches in diameter. The upper ends of the six wires were brought together and attached to three porcelain insulators connected in series. The lower end of the cage was tied off with three more insulators and the same six antenna wires were carried to the lead-in which was a cage twelve inches in diameter. Ground connections were made to a "coal

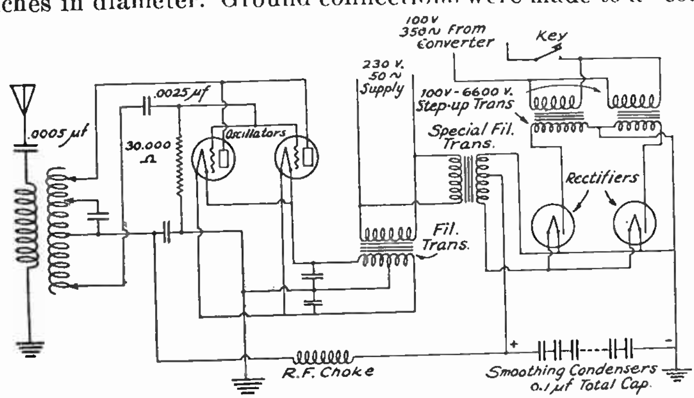


Fig. 322a. Circuit Arrangement of English Amateur Station which Successfully Bridged the Atlantic.
(QST, June, 1923.)

conveyor," and six wires were also taken down to a water main which passes underneath the station, and in addition a copper strip was run down to the river and connected to brass plates sunk in the mud of the river bed. Altogether there were three earth connections and the best results in transmission were obtained with these connected in parallel. Power was obtained at 230 volts, 50 cycles. This was used to drive a rotary converter, giving 350 cycles at 100 volts.

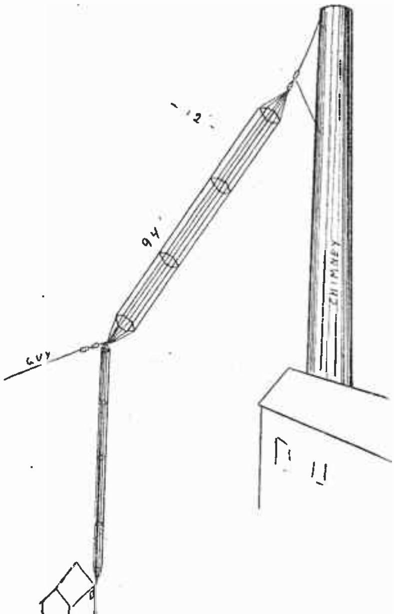
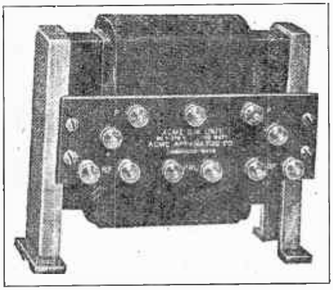


Fig. 322b. Type of Antenna Employed at the Station 5WS in England.

The transformers were manufactured for 350 cycles and 100 volts input and 6,600 volts output. Trouble was experienced with heating of the rectifier transformer, so a special-filament transformer was used, made to stand higher voltage. After experimenting with various circuits, the one finally selected was the Hartley. It was used with two Marconi-Osram valves capable of dissipating about 450 watts on the plates. The fundamental wave length of the antenna was 200 meters (1,500 kilocycles). The antenna current was 4½ amperes. The antenna resistance was about 30 ohms, which gave about 700 watts in the antenna.



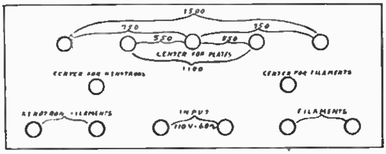


Fig. 323a. Acme Tapped Transformer.

	Specifications for Plate and Filament Transformer. (Acme)				
Size	Plate Volts on Each Side of Center	Max. Plate Current.	Filament Voltage.	Max. Fil. Current.	Number of Tubes.
600	1500, 1000	.300	12	13	two 50s
300	1100, 750	.250	10	5	four 5s
200	750, 550	.250	10	5	four 5s
75	375	.100	10	5	two 5s

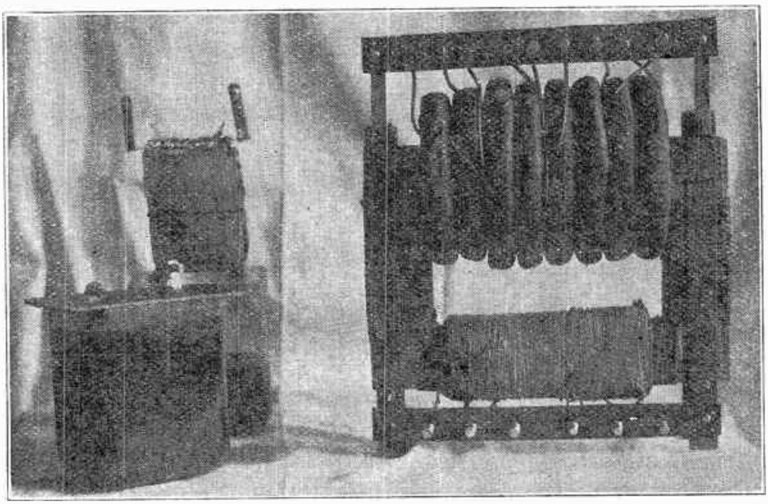


Fig. 323b. A 2000-Volt Mid-Tapped Plate Transformer and an Oil-Glass-Plate Condenser, made by Students in the Loomis Radio College.

Transformers used in amateur transmitting stations may be factory built, or they can be successfully made at home by anyone with a little mechanical ingenuity. A transformer for two 50-watt tubes, using full-wave self rectification was made by students in the Loomis Radio College as follows: The core was constructed as in figure 323b. It was made of thin transformer iron, two sides made of 75 pieces, each 12 by 2 inches, and the other two sides of 75 pieces, each 8 by 2 inches. These were "log cabined" at the corners, tied with stout twine, then one of the longer sides carefully removed. The primary was wound over one of the shorter sides still remaining in the form. This consisted of 400 turns of No. 14 d.c.c. copper wire, carefully insulated from the core with yellow empire cloth, and covered with friction tape. The secondary pies were wound inside a wooden frame built for the purpose, and are about 6 inches in diameter and 1 inch thick. A piece of string was laid inside of the form before starting to wind, so that the pie could be removed after one end of the wooden frame had been loosened. Each pie consists of 1200 turns of No. 24 d.c.c. wire, covered with cotton tape and then shellacked. Four pies are arranged for each half of the center-tapped transformer, and additional taps are made from each pie so that they may be reduced in number if desired. After the remaining long piece of the laminated core was covered with empire cloth, the pies were carefully slipped over this, connected in series, through the taps taken out to the binding posts, and a piece of bakelite holding binding posts fastened across the top of the frame which holds the core. This was made to use on the output of a 120-cycle 110-volt alternator. The voltage across each half is 1100, and 2200 volts are obtainable across the outside leads.

The condensers are made of sheet copper and discarded photograph plates tied together with twine and immersed in transformer oil. The plates were cleaned with sulphuric acid solution.

Experience shows that with some types of vacuum-tube transmitters, especially the full-wave self-rectifying circuits, it is best to arrange the plate and filament transformers separately, as in figures 322a and 493. Otherwise there is difficulty in preventing the tube filaments from flickering when the load on the plate is changed by opening and closing the transmitting key. This is more pronounced with some key locations than with others.

TABLE OF SPECIFICATIONS FOR THREE TRANSFORMERS CAPABLE OF SUPPLYING POWER FOR FOUR 5-WATT, TWO 50-WATT AND TWO 250-WATT TUBES, RESPECTIVELY.

(From Stuart Ballantine's *Radio Telephony for Amateurs.*)

Rating of Power Tubes.	5 w.	50 w.	250 w.
Power rating	250 w.	700 w.	2200 w.
Normal primary voltage	110 v.	110 v.	220 v.
Primary current (full load)	2.5 a.	6.5 a.	10.8 a.
Efficiency	90%	90%	90%
Primary turns for 102 volts	306	204	204
" " " 105 "	315	210	210
" " " 108 "	324	216	216
" " " 110 "	330	220	220
" " " 112 "	336	224	224
" " " 115 "	345	230	230
Primary conductor (B. & S.)	No. 14	No. 12	No. 10
Amount of wire required	4½ lbs.	3½ lbs.	7 lbs.
Filament secondary voltage	8 v.	10 v.	11 v.
Filament current	10 amp.	13 amp.	30 amp.
Filament secondary turns	24	20	11
" " conductor	3 No. 14 in parallel	3 No. 12 in parallel	*Note 1*
H. T. secondary voltage, E_1	400 v.	1200 v.	2200 v.
" " " E_2	500 v.	1500 v.	2600 v.
" " " E_3	700 v.	1700 v.	3000 v.
H. T. secondary turns; Tap No. 1	450	400	400
" " " " No. 2	900	1000	800
" " " (Center tap); No. 3	2100	3400	3000
" " " Tap No. 4	3300	5800	5200
" " " " No. 5	3750	6400	5600
" " " " No. 6	4200	6800	6000
H. T. sec. conductor (B. & S.)	No. 28	No. 28	No. 24
Amount of wire required	2 lbs.	3¼ lbs.	9 lbs.
Core dimensions (a x b)	4" x 2½"	4" x 3"	5½" x 3"
Core cross-section	1½" x 1½"	1¾" x 1¾"	2½" x 2½"

Note 1.—In the case of the 2200-watt transformer for two 250-watt tubes, the 220-volt supply is recommended. For 110-v. operation, in lieu of 220-v., wind primary in two sections and connect in parallel, or wind with half the above number of turns with copper ribbon ¼" x ³⁄₃₂" cross-section.

FILAMENT TRANSFORMER

Suitable for Supply of Two 5-, 50- and 250-Watt Tubes.

Power.	5 w.	50 w.	250 w.
Power rating	40 w.	200 w.	440 w.
Efficiency	75%	85%	85%
Primary voltage (60 cycles)	110 v.	110 v.	110 v.
Secondary voltage	10 v.	13 v.	13 v.
Primary turns	500	500	250
Primary conductor (B. & S.)	No. 22	No. 16	No. 12
Secondary turns	45	60	30
Secondary conductor (B. & S.)	No. 12	6 No. 16 in parallel	6 No. 12 in parallel
Amount of wire required	P. 1¼ lbs. S. 1 lb.	6 lbs.	7 lbs.
Core dimensions (a x b)	2½" x 1½"	3" x 3"	3" x 3"
Core cross-section	1" x 1"	1½" x 1½"	2" x 2"

328. In figures 313 and 315 the modulating effect of alternating current upon continuous oscillations was illustrated. It can be seen that any influence which can vary the plate current can cause the oscillations produced by the tube to rise and fall in amplitude and wave shape in unison with this change. This fact is the basis of many systems of communication with vacuum tubes, including telephony. *Modulation is the process of superimposing variations of audio frequency upon an alternating current of radio frequency.* This is not the same thing as producing a *beat note* as in the heterodyne, where the two frequencies *combine* until they *overlap.* Modulation does not cause a *beat,* but *varies the amplitude of the continuous oscillations so that in their rising and falling fluctuations they exactly reproduce the frequency and wave form of the rising and falling amplitude and wave form of the modulating influence.* The continuous oscillations may be thought of as a plastic substance, which is formed into different wave shapes by the impressed modulating influence. An interesting method of producing modulation of the continuous oscillations is illustrated in figure 324. It is simplicity itself. A solenoid connected in series with a low powered alternator of about 500 cycles is wound around the outside of an oscillating vacuum tube. The magnetism of the solenoid penetrates the glass of the tube, and the frequency of the alternator is impressed upon the electron flow within the tube. This idea is not practicable for high-powered transmitters, but can be used successfully with low power. Waves of unmodulated and continuous amplitude would be radiated with the key open, and when the key is closed a signal is radiated which is similar to that illustrated in figure 315. These signals can be heard in any plain receiver not equipped for receiving continuous waves. Also, a regenerative receiver might catch the carrier waves, which would sound like a clear whistle. In all forms of modulated continuous-wave communication, the continuous wave, which would be of equal amplitude were it not for the superimposing of the

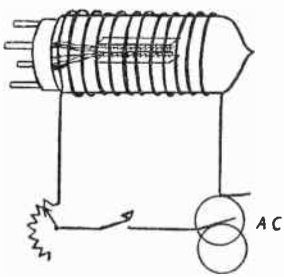


Fig. 324. Magnetic Method of Modulating the Electron Stream of a Vacuum Tube. (Bureau of Standards.)

local influence having audible-frequency variations, is called the *carrier wave.*

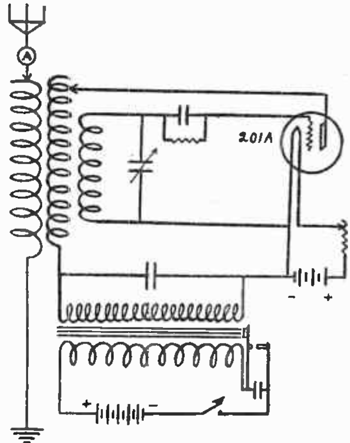


Fig. 325. Spark-Coil Vacuum-Tube Transmitter.

A chopper or buzzer connected in series with, or inductively coupled to, the antenna, may be used for making the output of a tube transmitter audible on a crystal-detector receiving set, if desired. While these are often referred to as modulation devices, they are, more strictly speaking, merely *interrupters.* The signals from a transmitter using interrupted continuous waves are illustrated in figure 228. Buzzer modulation has been used in the U. S. Signal Corps, and to some extent in the Navy.

An arrangement which is strictly in the amateur class is illustrated in figure 325. Here an ordinary "spark coil" is connected as plate supply for a low powered tube, and the signals are sent out in audible groups of oscillations corresponding to the frequency of vibration of the magnetic interrupter on the coil. In this, the transformer raises the voltage of the lower powered battery circuit, so that it is suitable for use on the plate of the tube.

329. There are several methods of modulation, which, as they are associated with the transmission of telephone sig-

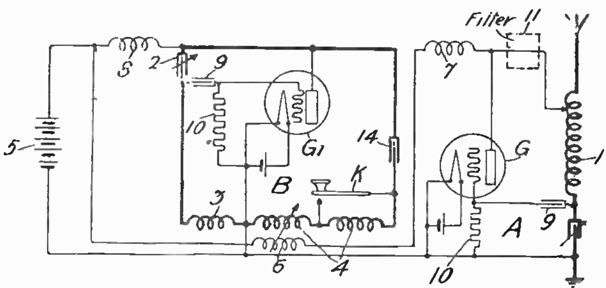
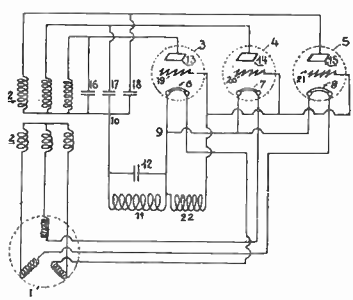


Fig. 326. Vacuum-Tube Transmitter Employing Heising Modulation. (Reproduced from patent granted Feb. 6, 1923.)

nals rather than with telegraph, will be taken up in the following chapter. One system of key signaling, where the *tone transmitter* consists of an apparatus employing two tubes, is given here. This is the *Heising system of modulation,* which is applicable to both telegraphy and telephony. Quoting from the patent specifications, "The system comprises a high-frequency generating system, A, and low-frequency generating system, B. In system A high-frequency oscillations are produced in the antenna circuit by the action of the electrionic discharge of the tube G. The frequency of the oscillations generated in the antenna is determined primarily by the tuning of the antenna. In system B tube G' generates oscillations in a tuned circuit consisting of variable capacity 2 and inductances 3 and 4. A key serves to short-circuit a portion of inductance 4 for the purpose of changing the frequency generated in system B. By thus changing the frequency, signals may be transmitted. Capacity 14 prevents the battery from being short-circuited. A filter or impedence device, 11, of any suitable type, which may be a loop resonant circuit tuned to the mean frequency of system B, prevents oscillations generated by system B from being impressed upon the antenna circuit. Filter 11 is not essential to the operation of the system and may be omitted if desired. During operation, the high-frequency oscillations of the system A are *modulated* in accordance with the oscillations of the system B. This is caused by the intercoupling of coils 4 and 6, whereby a voltage corresponding to the low-frequency oscillations is impressed upon the space between the anode and cathode of tube G."



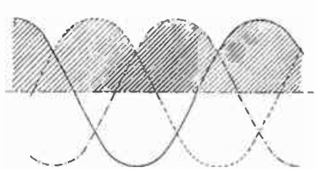


Fig. 327. Bouchardon System for Utilizing Three-Phase A. C. for Vacuum-Tube Transmitter.

330. Figure 327 shows the circuits of a self-rectifying oscillating circuit, patented by V. J. Bouchardson, of Lyons, France, and the representation of the rectified current. In this system the cir-

cuit consisting of the condenser, 12, and the inductance, 11, is the oscillating circuit. If antenna and ground are connected to these coils, and an appropriate keying system added, this becomes a practical transmitter. The capacity of the antenna may replace capacity 12. 1 may be either a 3-phase alternator armature, or connection to a three-phase power line. The filaments are star connected, the neutral point being at 9. 10 is the neutral point of the step-up transformer. Condensers 16, 17 and 18 are to allow the high-frequency oscillations of the plate current to pass. The three grids are in parallel to the neutral point 9, through the coil 22. Referring to this Mr. Bouchardon says: "The use of the three-phase current has the following advantage over the simple alternating current (single phase) even by using two lamps in the monophase circuit, each plate connected to one end of the secondary of the transformer, the middle part of which would be connected to the filament. With the single-phase current, the oscillations cease as soon as the voltage is no longer high enough for maintaining them. Consequently, the oscillations are not continuous, but are interrupted at each alternation during a certain time. Figure (327) shows that with a three-phase current the oscillations are continuous. The arrangement in parallel of the three grids compels them to oscillate synchronously, the valve, the plate potential of which is the strongest, thus helping to maintain the oscillations in the valve, the plate potential of which is not yet sufficient. The transition from one valve to the other is thus perfectly insured."

331. Three-phase alternating current, when properly rectified, provides a smoother direct current than that obtained by the usual rectifying systems with single-phase current.

The mercury-vapor rectifier, which is shown in figure 600 as employed in a storage-battery charging outfit, is often used for rectifying high-voltage power for vacuum-tube plates. It is necessary to employ some sort of "keep-alive" arrangement to prevent the arc through the bulb from stopping when the output circuit is opened. This may be a resistance, or kenotron tubes as shown in figure 329a. This system is not very efficient, considering input and output ratios, but when properly filtered the output is the best of d.c., which is under some circumstances worth wasting power to obtain. The average current in the keep-alive circuit is about 2.3 amperes. The mercury-arc bulb is immersed in oil to prevent the heat of the keep-alive circuit from breaking it. Figure 329b shows how this bulb may

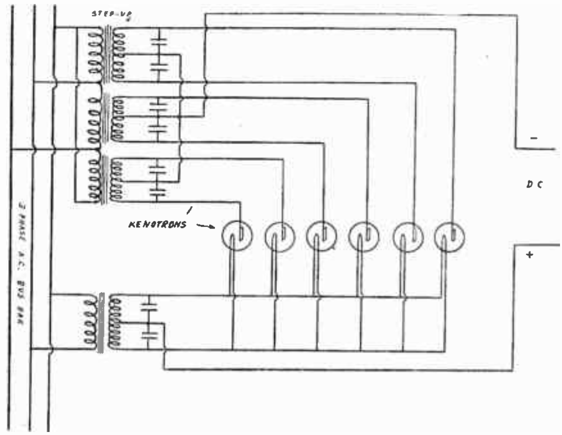


Fig. 328. A Kenotron System for Rectifying Each Half of Each Phase of a Three-Phase Current.

be used for three-phase current. At A a three-phase induction motor is connected so that its field windings will change a single-phase current to three-phase, which provides a power

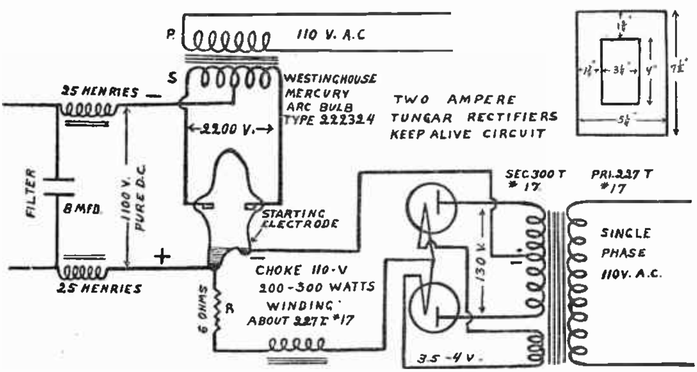


Fig. 329a. Mercury-Arc High-Voltage Rectifier for D. C. Plate Supply. (Used for d. c. plate supply of 50-watt tube transmitter at Station 3TD.)

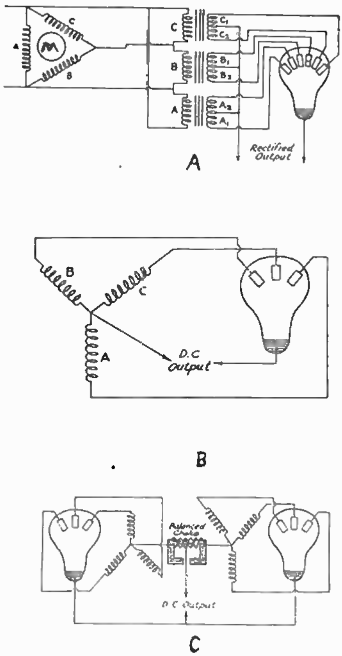


Fig. 329b. Three-Phase Connections for Use of Mercury-Arc Valve.
(QST, April, 1924.)

supply suitable for pure continuous-wave transmission or radiotelephony. C is the rectifying system used for the telephone broadcasting station at WGY.

332. The antenna inductance should add as little resistance to the antenna circuit as possible, and dielectric losses due to capacity between the coil and the ground, or adjacent pieces of apparatus, may be reduced by surrounding the coil with a grounded screen made of a piece of coarse iron-wire netting, left open about an inch on one side to prevent eddy currents. This is called a magnetic shield. For a low-powered transmitter a helix, about 7 inches in diameter, composed of 40 turns of a conductor made of seven strands of No. 18 enameled wire, may be used.

Choke coils used in tube transmitters vary in material, size of wire and number of turns, according to their purpose and location, and they may or may not have iron cores. With the larger ones it is advisable to make them variable. The filter-circuit choke coil usually has an inductance of about 50 henrys, and is wound over an iron core, from which the windings are insulated. In some filters two chokes, of 30 and 15 henries, are connected in series with a condenser across the circuit between them. For a 5-watt tube, drawing about .1 ampere, approximately 50 henries may be obtained by winding $2\frac{1}{4}$ pounds of No. 30 insulated wire over a tube 2 inches in diameter. For a 50-watt tube, drawing .3 ampere, No. 24 wire is used, and for a 250-watt tube requiring .6 ampere, No. 22 wire. Where pure inductance is desired, such as in choke coils, bank windings are used. This is the most effective method of reducing the capacity between the wires composing the coil. This is illustrated in figure 330a. After the first two turns are made, the third turn is lapped back to fill the ridge made between the coils 1 and 2, and then the back-lapping of every other turn is continued throughout the coil. Especially prepared tubes of fiber or hard rubber, with surfaces scored in fine grooves for the purpose of holding the first layer of banked coils, are sold in many stores. Covering the tubing with friction-tape before winding will also prevent the first layer of wire from slipping. By arranging the iron core so that a small air gap may be obtained on one side of it, heating is re-

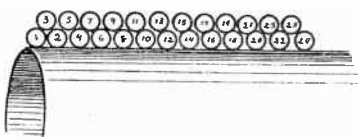


Fig. 330a. Cross-Section of Bank-Wound Inductance Coil.

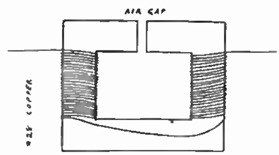


Fig. 330b. Iron-Core Choke Coil with Air Gap.

duced. This may be made variable by using a small piece of iron for a wedge, which may be pressed into the air gap, or drawn out of it. This varies the inductance within limitations. Taps may also be used for varying the inductance of a choke coil. The choking effect depends upon the frequency of the circuit in which the coil is used. The lower the frequency, the higher must be the inductance for effective functioning of a choke coil. With an inductance coil of proper value and a condenser of appropriate capacity we have a filter circuit which may be tuned to actually filter out fluctuations of a particular frequency which it is desired to suppress (see paragraph 181). In a vacuum-tube transmitter employing such a filter the current of the oscillation frequency through the tube is drawn from the plate supply, but the low-frequency pulsations cause by rectifying an alternating-current supply or by a direct-current generator commutator ripple, are eliminated. The radio-frequency choke coils used in tube transmitters have usually an inductance of about 3 millihenrys, and are made of one layer of insulated copper wire, No. 28 or 30, wound over an insulating base about 2 inches in diameter and 7 or 8 inches long.

333. In the construction of tube transmitters, the constants of the various materials must be given consideration, and the size of wire must be in proportion to the current which it is required to carry. The *effective resistance* of a wire in a high-frequency circuit increases with an increase in frequency, due to the skin effect of alternating current, and also to some extent to the effect of capacity between adjacent wires. The higher the frequency of the current, the less can the current penetrate the material composing the conductor. Hence increasing the frequency, with any given conductor in the circuit, has somewhat the same effect as reducing the size of the conductor. This effect is more pronounced with some materials than with others, according to their degree of permeability. For this reason flat strips of copper "ribbon" are generally employed in places where a heavy current is to be carried at a high frequency. It is also found useful in many other portions of the high-frequency circuit, and has been successfully used for antennæ. Stranded copper wire, with the separate wires enameled, so as to be insulated from each other, is also a better conductor of the high-frequency current than a solid wire. One type of stranded silk-covered enameled wire is known as Litzendraht. In the U. S. Navy, much woven wire braid is employed. The following table, from the Bureau of Standards' *Circular No. 74,* gives the diameter in *centimeters* of different materials required to maintain a resistance ratio of 1.01 at different frequencies. The centimeter measurement for the diameter of the wire is international. The size of the wire, according to the American wire gauge, can easily be determined by the usual methods, after its centimeter diameter is determined, if desired. Micrometers are obtainable which give the diameters of the wires in centimeters instead of in thousandths of an inch. In this table the Greek letter μ (mu) is used to indicate the permeability of the material. With R representing the direct-current resistance of the wire, and R′ representing the high frequency resistance, the ratio of the high-frequency resistance to the direct-current resistance is equal to

$$\frac{R'}{R}.$$

MAXIMUM DIAMETER OF WIRES FOR HIGH-FREQUENCY RESISTANCE RATIO OF 1.01

(Circular of the Bureau of Standards)

Frequency ÷ 10^6	0.1	0.2	0.4	0.6	0.8	1.0	1.2	1.4	1.6	1.8	2.0	3.0
Wave length, meters	3000	1500	750	500	375	300	250	214.3	187.5	166.7	150	100
MATERIAL	DIAMETER IN CENTIMETERS											
Copper	0.0356	0.0251	0.0177	0.0145	0.0125	0.0112	0.0102	0.0095	0.0089	0.0084	0.0079	0.0065
Silver	.0345	.0244	.0172	.0141	.0122	.0109	.0099	.0092	.0086	.0082	.0077	.0063
Gold	.0420	.0297	.0210	.0172	.0149	.0133	.0121	.0112	.0105	.0099	.0094	.0077
Platinum	.1120	.0793	.0560	.0457	.0396	.0354	.0323	.0300	.0280	.0264	.0250	.0205
Mercury	.264	.187	.132	.1080	.0936	.0836	.0763	.0706	.0661	.0623	.0591	.0483
Manganin	.1784	.1261	.0892	.0729	.0631	.0564	.0515	.0477	.0446	.0420	.0399	.0325
Constantan	.1892	.1337	.0946	.0772	.0664	.0598	.0546	.0506	.0473	.0446	.0423	.0345
German Silver	.1942	.1372	.0970	.0792	.0692	.0614	.0560	.0518	.0485	.0458	.0434	.0354
Graphite	.765	.541	.383	.312	.271	.242	.221	.204	.191	.180	.171	.140
Carbon	1.60	1.13	.801	.654	.566	.506	.462	.428	.400	.377	.358	.292
Iron $\mu=1000$	0.00263	0.00186	0.00131	0.00108	0.00094	0.00083	0.00076	0.00070	0.00066	0.00062	0.00059	0.00048
$\mu=500$	.00373	.00264	.00187	.00152	.00132	.00118	.00108	.00100	.00093	.00088	.00084	.00068
$\mu=100$	.00838	.00590	.00418	.00340	.00295	.00264	.00241	.00223	.00209	.00197	.00186	.00152

(Note. The appendix contains a table giving millimeter equivalents of thousandths of an inch.)

334. In the installation and operation of vacuum-tube transmitters, certain general rules should be observed. Adjustment should be made which, at a minimum of plate voltage and filament current, will give the greatest possible output. While the antenna input may be determined by the hot-wire ammeter located in that circuit, this does not always indicate the radiation of energy from the antenna, as much power may be lost due to high antenna resistance and poor grounding. The simplest method of determining how the radiation compares with the antenna input is to establish communication with two or three stations at different distances, and ask them to check on the energy of your signals in their receivers. The resistance of the antenna conductors changes with the wave length according to the table given in paragraph 333. Vacuum tubes are better suited for operation on short wave lengths than are the older spark sets, and the antenna should be designed with a view to the wave length to be used (see paragraph 273). It is wise to place a fuse in series with the plates of the tubes having more than 5 watts power output. Appropriate fuses may be purchased, or they may be made from tinfoil. The tinfoil melts easily if an overload of current passes over it. The right size may be determined by experimentation. If a memorandum of the size of the strip is preserved, it is thereafter only necessary to cut a new fuse as needed. The tinfoil is easier to handle if pasted to bristleboard. Contact is made with small clips. Protection of the high-frequency circuits is obtained by placing a safety gap between the grid and the filament to take care of any sudden rise in the voltage in this part of the apparatus. Overload circuit-breakers are used in the plate circuits of high-powered tube transmitters. (See paragraph 490.)

The grid leak must be of the proper resistance for best operation of the apparatus. For one 5-watt tube this should be from 5,000 to 10,000 ohms. For several 5-watt tubes in parallel, a lower resistance may be necessary, or a separate leak for each tube. The more current to be passed through the leak, the lower must its resistance be.

*One planning to install an amateur transmitting station should become acquainted with the rules regarding such stations, as issued by the Department of Commerce, and these rules should be carefully complied with.**

*The following extracts from General Letter No. 265, issued by the Department of Commerce December 24, 1924, cover the regulation of amateur radio activities. The year 1926 brought a change in policy of the Department of Commerce, resulting in greater freedom for owners of radio stations in the matter of wave lengths. However, these fundamental rules will apply for many years, and station owners who have become known would not care to change their wave length. Neither would they care to cause interference during church services or broadcasting hours, even though the "silent hour" is no longer required.

TO SUPERVISORS OF RADIO AND OWNERS OF AMATEUR RADIO STATIONS—REGULATIONS GOVERNING THE OPERATION OF AMATEUR STATIONS.

Wave Lengths

150 to 200 meters, 75 to 85.7 meters, 37.5 to 42.8 meters, 18.7 to 21.4 meters and 4.69 to 5.35 meters are allocated to amateur stations.

Spark Transmitters

Amateur spark transmitters produce considerable interference and consequently are responsible for many complaints. Amateur owners of such transmitters should abandon their use as early as possible and adopt a system producing less interference. Until such change is made they will be permitted in the wave length band between 170 and 180 meters and should have a decrement not exceeding .1.

Phone and ICW Transmitters

Phone and ICW (Interrupted Continuous Wave) transmitters will be permitted in the band from 170 and 180 meters. ICW shall be defined as the type of wave produced by mechanically interrupting one or more of the radio-frequency circuits or the type of wave produced by any transmitting set which produces an equivalent effect.

CW Transmitters

CW (Continuous Wave) transmitters will be permitted in all of the bands allocated for amateur use.

Coupled Circuits

Amateur stations must use circuits loosely coupled to the radiating system, or devices that will produce equivalent effects to minimize key impacts, harmonics and plate supply modulations, except in cases where loops are used as radiators. Conductive coupling, even though loose, will not be permitted.

Power Supply

No restrictions will be imposed relative to the character of power supply, provided the emitted wave is sharply defined.

Station Licenses

Licenses issued for amateur stations will authorize the use of any or all of the wave lengths allocated for amateur use, provided the transmitter meets the requirements of the above regulations. No alteration in the apparatus will be permitted which results in changing the character of the emitted wave, except under authority granted by the Supervisor of Radio.

Intercommunication

Amateur stations are not permitted to communicate with commercial or Government stations unless authorized by the Secretary of Commerce, except in an emergency or for testing purposes. This restriction does not apply to communication with small pleasure craft such as yachts and motor boats, which may have difficulty in establishing communication with commercial or Government stations.

(Signed) *A. J. TYRER,*
Acting Commissioner.

Approved:
S. B. DAVIS, JR.,
Acting Secretary of Commerce.

335. A new type of vacuum-tube transmitter, designed especially for communication with airplanes, was developed by Mr. Francis W. Dunmore, at the radio laboratory of the Bureau of Standards in Washington. This transmits on a wave length of 100 meters, and is used in connection with a directional antenna of novel construction. The grid

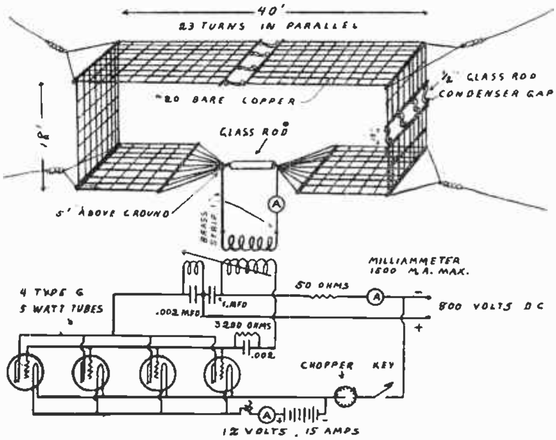


Fig. 331a. Circuit Diagram of 100-Meter Transmitter. (Bureau of Standards.)

coil consists of a "pancake" spiral of ½-inch copper strip, spaced five-sixteenths of an inch apart. The 100-meter tap is on the sixth turn of this coil. The plate coil consists of two turns of copper strip two inches wide, spaced 1¼ inches; and the secondary consists of three turns of flexible brass strip 1 inch wide spaced 1¼ inches. The outside dimensions of these coils are 10 inches for the grid coil, 11 inches for the plate coil, and 12 inches for the antenna coil.

336. New developments in connection with *high-frequency* transmission are taking place at a rapid rate. There is a greater penetration for a given power input when extremely high frequencies are used; and this advantage will, no doubt, influence the design of transmitting apparatus in the future. One of the difficulties encountered in experimenting with short-wave transmitters has been in securing *absolute stability of frequency,* where slight changes make such a noticeable difference. Working along these lines, several prom-

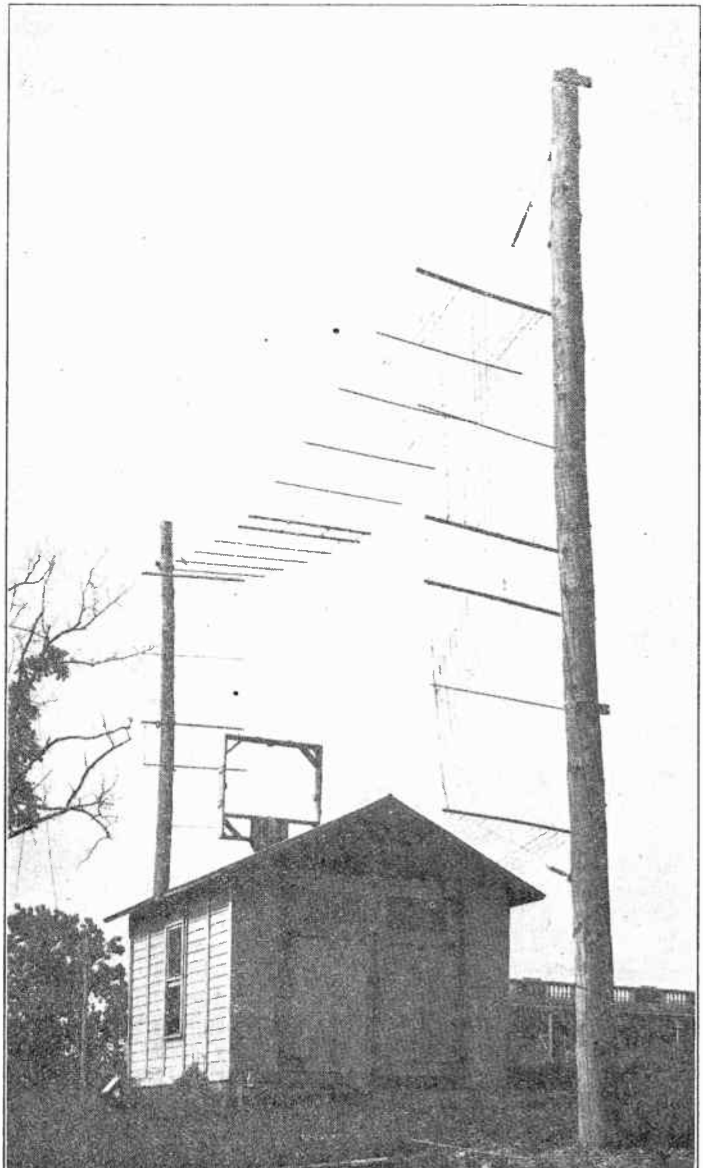


Fig. 331b. Photograph of Directional Antenna Used with the 100-Meter Transmitter of the Bureau of Standards.

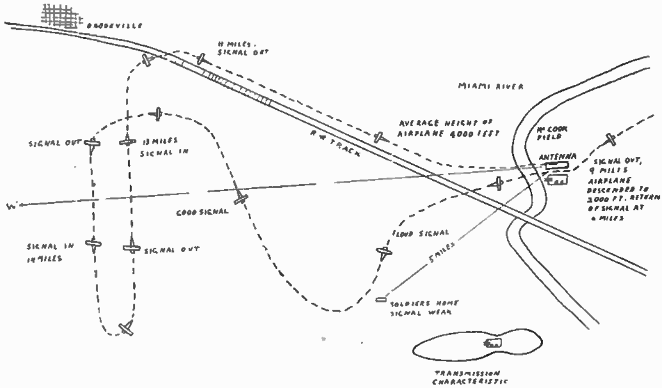


Fig. 331c. Directional Characteristics of the Transmitter Shown in Figure 331a, as Determined by Test Made with a Moving Airplane.
(Furnished by Bureau of Standards.)

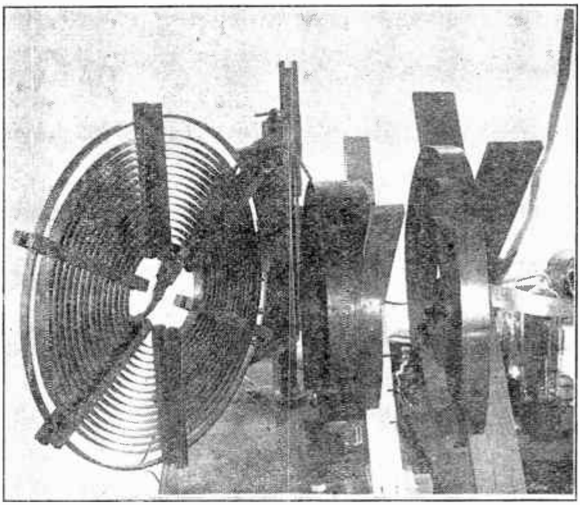


Fig. 331d. Coils Used in 100-Meter Transmitter.
(Bureau of Standards.)

inent experimenters have proved that *quartz crystal* can be made to oscillate, and used advantageously in a short-wave vacuum tube transmitter. Quartz, Rochelle salts and some other crystals have the property of becoming electrically charged when compressed, and of changing their shape slightly when they are charged electrically. They will produce an alternating voltage if mechanically vibrated and will vibrate if subjected to an alternating electrical field. These effects are known as "Piezo electricity." The peculiarity of the quartz is that it has *one natural period* of oscillation, dependent on its size, and can only be made to change its frequency by changing its size or shape. In these experiments, to date, it has been found that the most efficient method of using the quartz crystal is as shown in figure 332. The quartz is used to produce the oscillations, and the tubes to magnify the power, on the master-oscillator principle. The crystal is about one and one-fourth inches in diameter and one-sixteenth of an inch thick. It is pressed lightly between two brass plates. Varying the antenna inductance and capacity merely varies the *power ouput,* according to the *resonance* obtained between this and the oscillating circuit. The wave length is not changed. In the diagram shown, two 5-watt tubes were used. The key was placed in the antenna circuit to avoid interrupting the oscillations produced by the crystal, as it takes it a short interval of time to "build up" each time after the circuit is closed. The wave length of this set is 95 meters, or 3,150 kilocycles.

In the manufacture of the crystals, they are ground down by hand with carborundum and emory, and tested in a vacuum-tube oscillating circuit to determine their frequency, until the desired period has been obtained. This can be done with accuracy down to about thirty-five meters.*

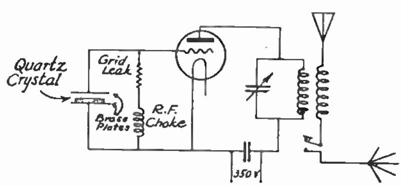


Fig. 332. Quartz Crystal Vacuum-Tube Short-Wave Transmitter. (Station 1XAU.) (QST.)

*See article by Dr. George W. Pierce, of Harvard University, in *Proceedings of the American Academy of Arts and Sciences*, October, 1923; article by W. G. Cody, of Wesleyan University, *Proceedings Institute Radio Engineers*, April, 1922, and article by H. S. Shaw, of the General Radio Company, in QST, July, 1924. Also, *Radio Broadcast*, January, 1927, article by Thornton Dow.

337. The advent of short-wave communication brought many changes in details of construction and in antenna systems. The antenna most frequently used with short-wave transmitters consists of a short vertical pipe, or heavy wire, with a counterpoise of the same. Heavy wire, wide strips of sheet copper, etc., are used for conductors, as they have lower resistance for the extremely high frequencies than other materials. Figure 333a is a photograph of the apparatus used at station 3BKC, which is making quite a record in long distance work on 40 meters. The transmitting aerial and counterpoise are each a 32-foot vertical wire. Following is a key to the diagram of this installation:

Transmitter

C1—11-plate double spaced condenser.
C2—33-plate double spaced condenser.
C3—.002-mfd. fixed condenser.
C4—.001-mfd. fixed condenser.
C5 and C6—2-mfd. filter condenser.
L1—14 turns (40-meter band).
L2—4 turns.
L3—40 turns (rf choke).
L4 and L5—1½ henry choke.
R—5000-ohm grid leak.
MG—6-180-volt dynamotor.

Receiver

C1—5-plate low-loss condenser (.0001).
C2—11-plate condenser (.00025).
C3 and C4—2-plate midget condenser.
L1—19 turns for 58 to 113 meters.
10 turns for 35 to 70 meters.
6 turns for 23 to 45 meters.
3 turns for 15 to 26 meters.
L2—3 to 6 turns.
A—15 feet No. 12 wire horizontal inside room.

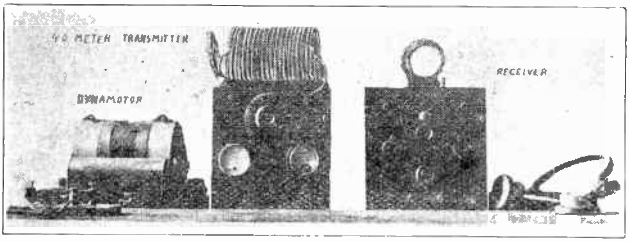


Fig. 333a. Photograph of 40-Meter Transmitting and Receiving Apparatus at Station 3BKC.

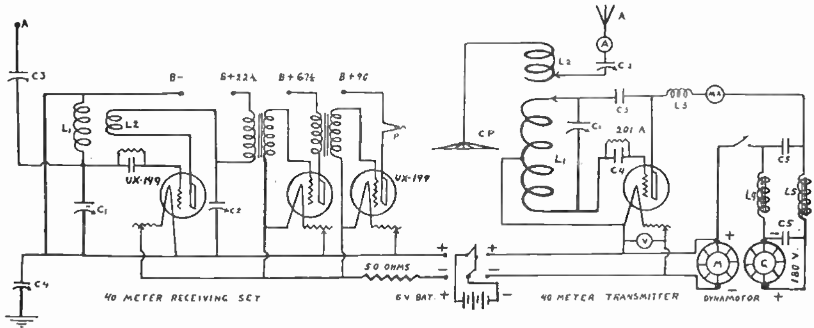


Fig. 333b. Wiring Diagram of Station 3BKC.

Capacity in the transmitting tube affects the frequency and special tubes are being brought out to meet the requirements of short-wave transmission. The De Forest Company has produced a new tube designed for operating on from 1 to 200 meters. It is known as the Type-H tube, has an input rating of 150 watts, and operates on 10 volts, 2.35 amperes filament power. The plate voltage is from 500 to 3,000 and plate current from 40 to 50 milliamperes.

338. Short waves have called attention to several facts hitherto not noticed, or considered especially important. The short waves "jump." That is, they exhibit the peculiarity of being heard at some point a great distance from the transmitter, while receiving stations much nearer may not hear the signals. This is accounted for by the reflection referred to in paragraph 189, which is much more pronounced on the high frequencies than on the lower ones. Some wave lengths fade more than others, and others most in the daytime, or at night. Signals of 100 meters give

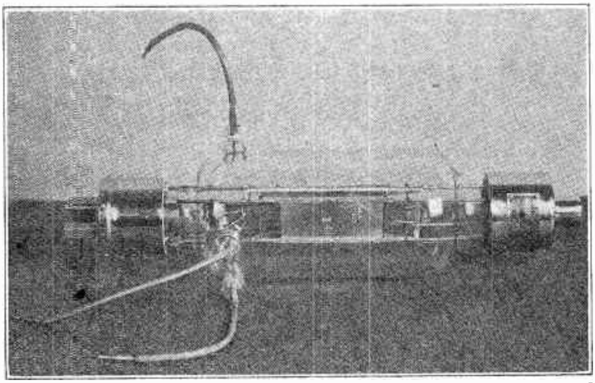


Fig. 334. The New De Forest Short-Wave Transmitting Tube.

remarkable distance during darkness, but extreme fading in the light. 50-meter signals travel farthest in the day-time and fade at night. Stations operating on 15 to 30 meters are often able to communicate across the oceans at noon. The exact explanation of these facts will probably be worked out in time. There is without doubt some effect of light rays upon radio waves, and some relation between the frequencies of the former and the latter which has something to do with the fading and "freak" phenomena of short waves. It has been found that short-wave transmission across the Pacific Ocean is easier than across the Atlantic, and gives different results in several ways.

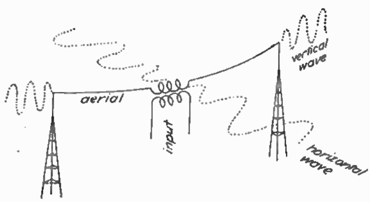


Fig. 335. Horizontally Polarized Waves as Radiated from Horizontal Antenna.
(Dr. E. F. A. Alexanderson, Radio Progress, Dec. 15, 1925.)

The General Electric Company has, at Schnectady, conducted extensive experiments and tests of short-wave transmission and reception. Three types of antennae were weeded out from the many tried. These may be classified as the straight vertical antenna made to oscillate at a harmonic of its natural period, the horizontal ungrounded antenna with a feed-coil at its center and known as the half-wave doublet, and the series tuned horizontal loop, consisting of a horizontal wire arranged in a circle and tuning condensers. The vertical antenna operating on a harmonic radiates *high-angle waves* without the usual ground wave which accompanies ordinary horizontal wire antennae. The

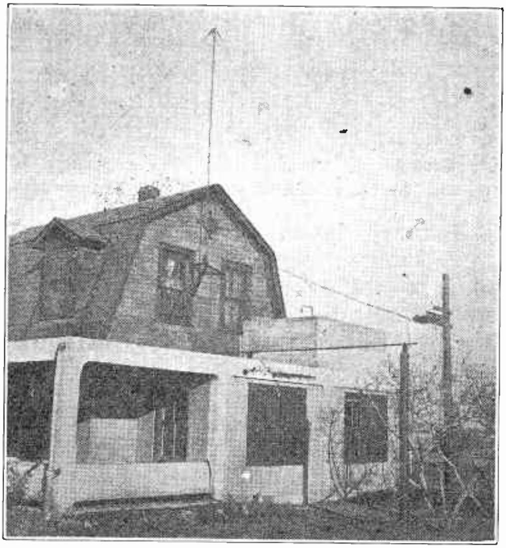


Fig. 336. Short-Wave Transmitting Station of the U. S. Signal Corps, Army Radio Net, WVB, at Fort Sam Houston, Texas, March 1st, 1926. Antenna and Counterpoise.

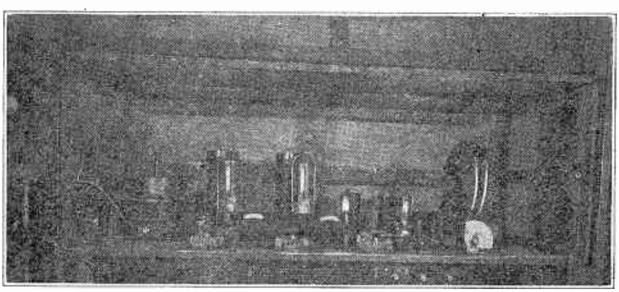


Fig. 337. 23-Meter, 400-Watt Transmitter at Fort Sam Houston Signal Corps Station WVB.

half-wave doublet radiates both high-angle and *horizontally polarized waves.* The horizontal loop sends out in all directions horizontally polarized waves only. There being no ends to the aerial, no high radiation can be emitted from it.

Present developments appear to be in favor of the horizontal wire with the center feed. The vertical wave is received best on a vertical antenna. A receiving antenna composed of a horizontal wire and counterpoise does not respond well to waves sent out from a vertical antenna, and the *horizontally polarized* waves emitted from the horizontal antenna are best received on a similar type of antenna.

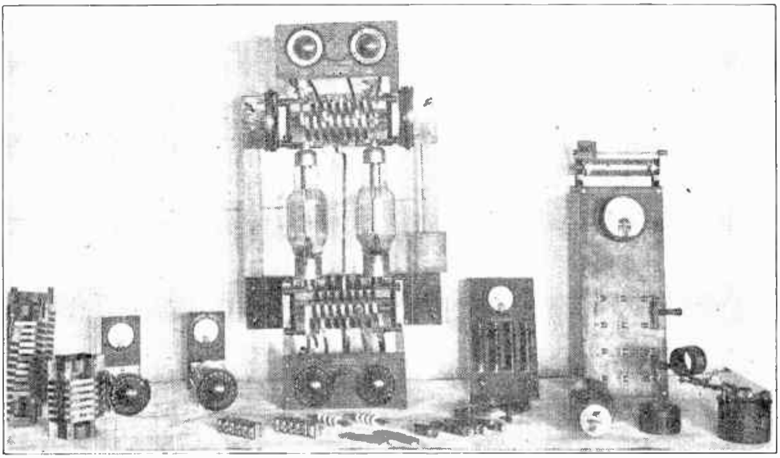


Fig. 338a. Short-Wave Transmitter Used on Board the S. S. Chantier of the Byrd Arctic Expedition, May, 1926—Station KEGK.

Dr. Greenleaf W. Pickard has found that short waves, when sent out vertically, do not remain so, but "after traveling 20 or 30 miles are in a large part twisted around so that they are horizontal." At his station at Seabrook Beach he has a receiving antenna composed of two short wires supported in a straight line, as in figure 335, with a superheterodyne receiver coupled to it at the center, and the antenna is mechanically arranged so that it can be rotated or turned at any angle. This is for the purpose of studying the effects of differently polarized waves on the receiving station. (See QST February, 1926, article by R. S. Kruse.)

Among the advantages of short-wave transmission over the longer waves are—a much greater distance covered for power input, a fair degree of secrecy, directional communication, and a reduction of static under some conditions. Among the disadvantages are the fading mentioned above and, under some conditions, a certain instability. However, there is no doubt but that the short-wave development marks the beginning of a new new era in radio work.

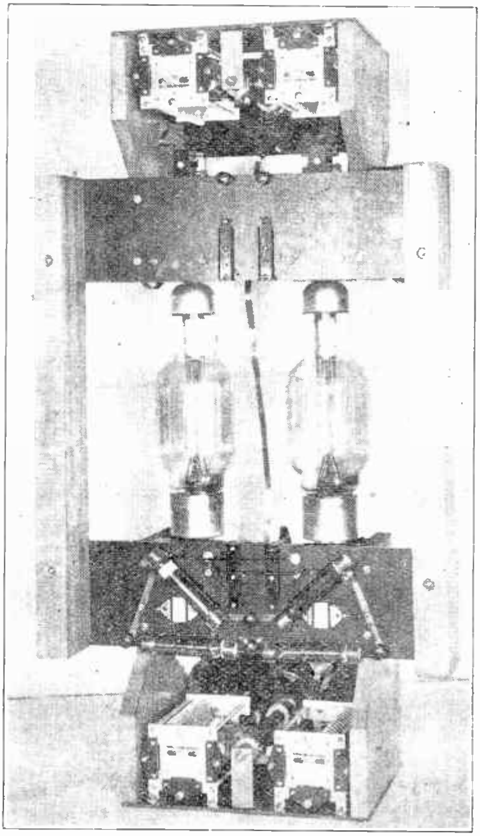


Fig. 338b. Rear View of the S. S. Chantier Short-Wave Transmitter.

339. While the first work in extremely short waves was connected with amateur and experimental stations, the U. S. Army and Navy have installed many auxiliary stations in this class. Figure 336 shows the 23-meter aerial and counterpoise used at the Army Radio Net station at Fort Sam Houston, Texas. They consist of two pieces of ¾-inch brass

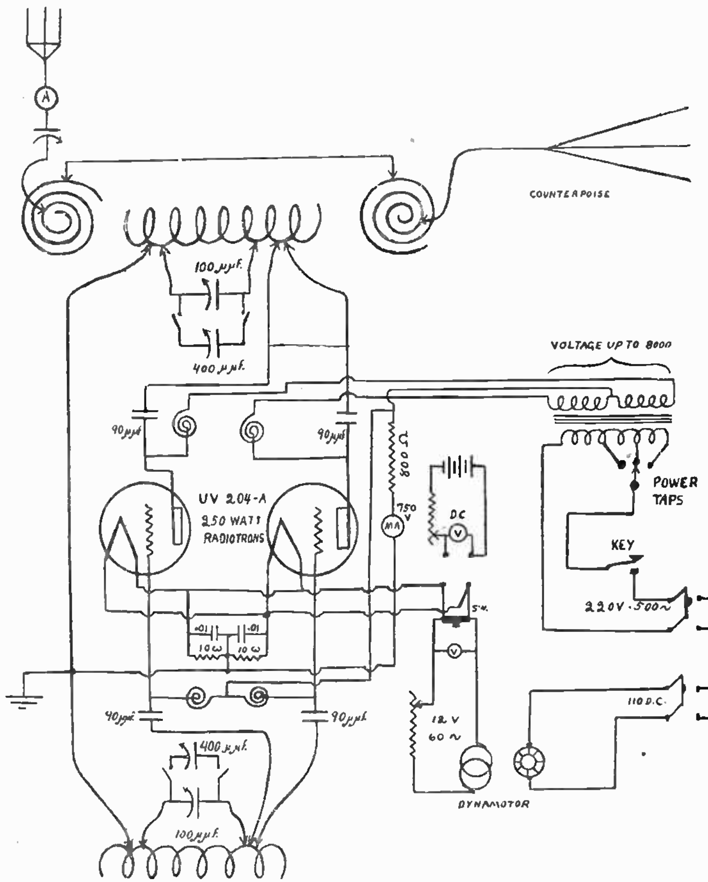


Fig. 338c. Wiring Diagram of Byrd Arctic Expedition Short-Wave Transmitter for 35 to 100 Meters.—KEGK.

(Tuned-plate-and-grid circuit with tube-capacity feed-back.)

pipe, each 20 feet long. The transmitting apparatus, located inside the window, is shown in figure 337. It is enclosed in copper screening, which serves as a shield.

While it was the first impression that short waves could not be handled practically with high power, this opinion has been changed. Condensers and inductances have been adapted for handling higher power on short waves, and there are a number of such stations now in operation in the Signal Corps. The Signal Corps 33.8 meter transmitter at the U. S. Navy Yard, WVA, has a power rating of 1 K.W.

340. Figures 338a and 338b are photographs of the short-wave transmitter which was privately designed by Malcolm P. Hanson, Radio Engineer of the Naval Research Laboratory

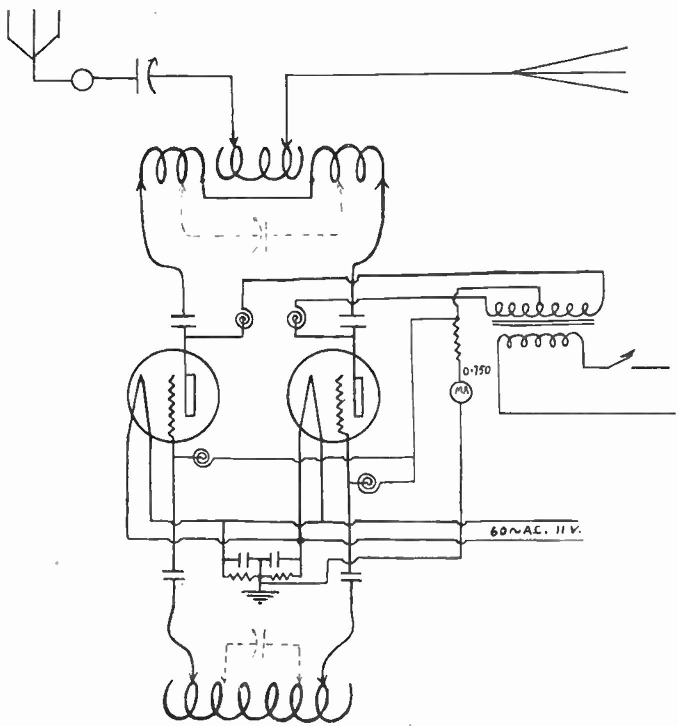


Fig. 338d. The Chantier Short-Wave Transmitter with Connections for 10 to 35 Meters.

at Bellevue, D. C., for the Byrd Arctic expedition. This transmitter derived its plate power from the 500-cycle alternator of the 1-K.W. Navy Standard spark transmitter on board. The filaments were lighted from a 60-cycle dynamotor, with emergency storage batteries to be used in case the dynamotor broke down. In this transmitter the capacity distribution in the tube replaces the usual ground. The plate circuit adjusts the tuning, and the grid circuit the efficiency. The arrangement of the variable condensers permits the use

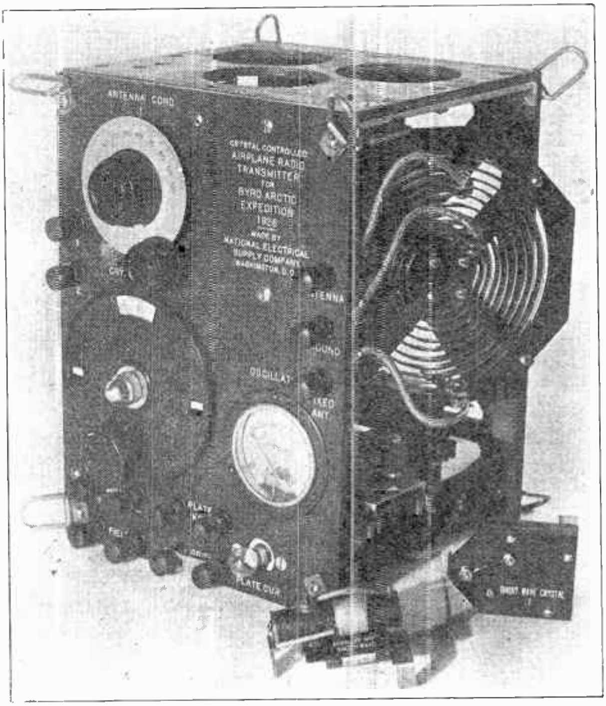


Fig. 339a. Crystal-Controlled Short-Wave Transmitter Carried on the Airplane in the Byrd Polar Expedition, May, 1926.

of the one having the wider spacing only, when the shortest wave lengths are used. The inductance coils are interchangeable, and are shifted for obtaining the different wave lengths. The apparatus has a range from 10 to 100 meters. The power rating is 500 watts; and the distance range 1000 miles or more. The complete equipment with plate milliammeter and plate fuses, filament rheostat and control switches, duplicate antenna ammeters with antenna tuning condensers, all mounted on separate panels, may be seen in figure 338a. At the extreme right is a small wavemeter.

A Grebe short-wave receiver was used in this installation.

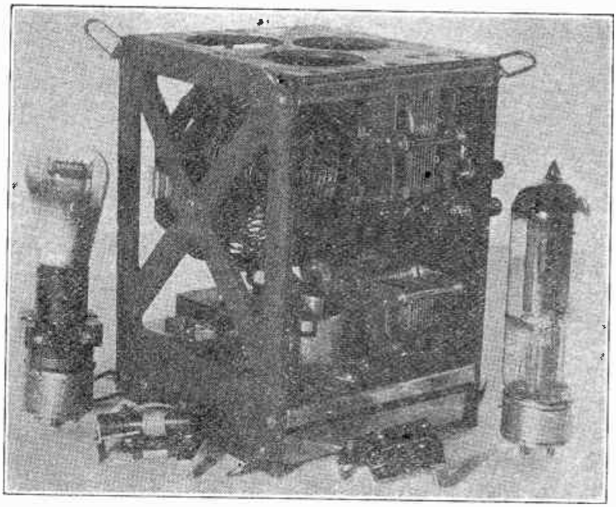


Fig. 339b. Rear of Byrd Expedition Airplane Transmitter.

Figures 339a and 339b are front and rear views of the airplane short-wave transmitter of the Byrd Arctic expedition.

Figure 339c is a transmitter of the same type mounted on the plane of the Wilkins expedition.

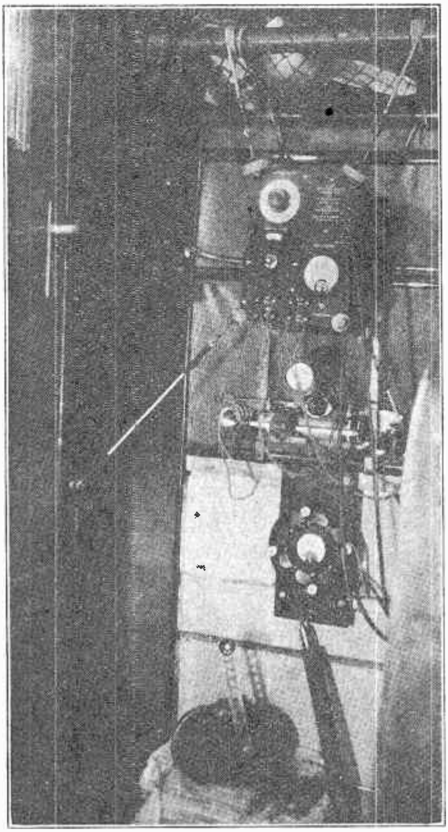


Fig. 339c. Short-Wave Transmitter on the Plane of the Wilkins Polar Expedition.

This was designed by Mr. Hanson, and constructed by the National Electric Supply Company, Washington, D. C., who also built the Chantier short-wave transmitter. The quartz crystal lying in front of the transmitter in Figure 339a is encased in a waterproof container to protect it from dampness in the air. An auxiliary unit, consisting of a small coil of wire and fixed condenser, having the same oscillation period as the crystal, was carried to be used in case of emergency. One 50-watt tube was employed. An auxiliary to this was a 7.5-watt tube, mounted in a 50-watt base, to be used with the hand-power type of auxiliary shown in figure 339d.

The requirements of a transmitter for such service are extreme compactness, lightness of weight, and such simplicity of operation that they can be operated by the pilot of the plane, who is rarely a radio operator, although required to know the code.

While a 50-watt tube is used in the airplane transmitter, the generator voltage is restricted to 400 to avoid strain on the crystal, but a heavy plate current may be drawn, and an output of 30 to 35 watts is obtained. To reduce sparking and

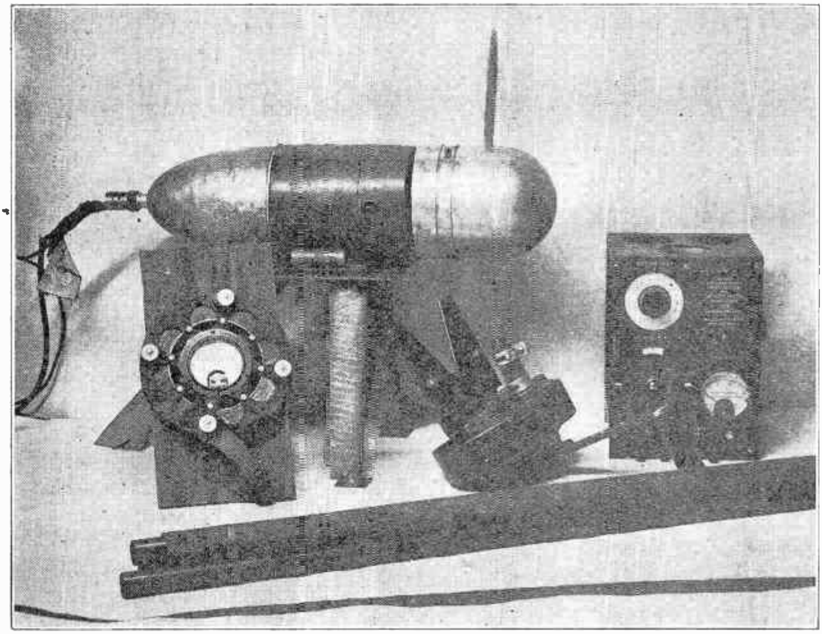


Fig. 339d. The Short-Wave Transmitter Used on the Plane of the Wilkins Polar Expedition, Generator, Hand Turning Mechanism, Antenna, Antenna Ammeter and Fairlead.

danger from high voltage in remote control operation, the grid circuit is keyed. Only one condenser is permanently connected in the circuit, all tuning being done by regulating the length of the trailing antenna (see figure 365).

All the power for this transmitter is obtained from a G.E. airplane generator mounted on a bracket on the fuselage. It has a single blade, the turning of which in the wind runs a fan motor. If required, on land, or in case of emergency, the generator may be driven by hand. As this is very hard work, the 7.5-watt tube mentioned above is used so as to draw less power.

The wave lengths employed with the airplane transmitters in these polar expeditions were 46 and 61 meters. A shorter wave length would have increased the distance, but would probably have shown skip zones, which were not permissible in the work with Point Barrow, Alaska.

341. One of the best known high-powered stations on the Atlantic coast is the Naval Transatlantic station at Arlington, Va.* Several transmitters, designed for different pur-

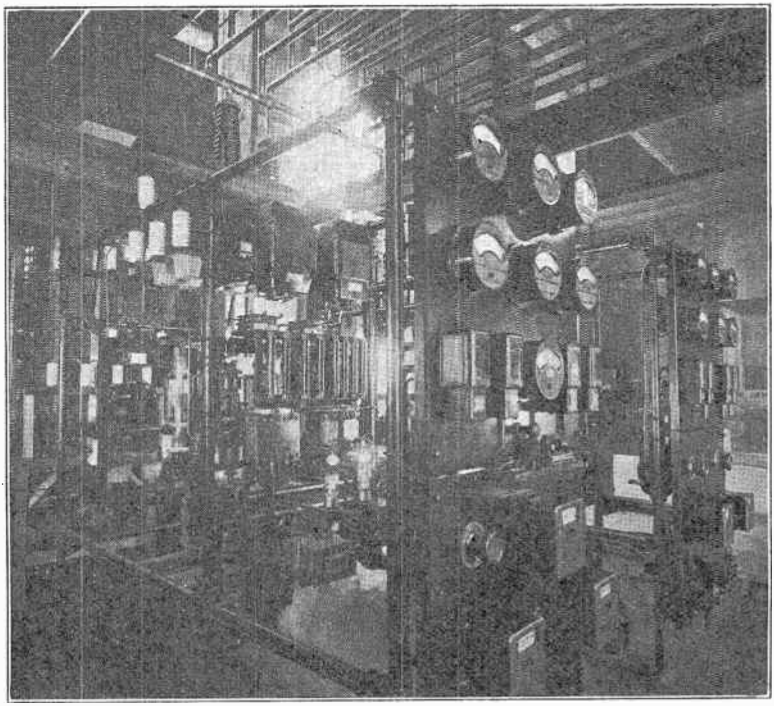


Fig. 340. A Corner in Station NAA.

poses, are installed at this station. In the main transmitter the master oscillator is employed, with a 5-K.W. oscillator feeding into a 20-K.W. power amplifier. A duplicate 20-K.W. water-cooled tube is installed. Two 20-K.W. rectifiers are used for pure C.W. on 8,200 meters for Trans-Atlantic communication only. At regular hours a 2,650 meter QST to ships at sea is transmitted. This includes orders for procedure of vessels, etc. At 10 P. M. the "time tick," by which masters of vessels, as well as many "landlubbers" set their timepieces, is broadcast on 2,650 and 435

*In December, 1926, the Navy Department announced its intention of moving the complete transmitting installation of NAA to the Navy Yard, Washington, D. C., to avoid interference from other stations which was affecting its efficiency, leaving the high towers at Arlington for receiving purposes.

meters simultaneously. The weather report on the same wave lengths follows this, after which communication with ships continues on 2,650 meters. For the 2,650 meter work, the transmitter is arranged as a full wave self-rectifiying circuit, carrying the tone of the 500 cycle a.c. supply. The 435 meter signals are sent on the telephone transmitter of the station, and the 500 cycle note is obtained by the use of a 500 cycle generator about 2½ inches in diameter, which is connected in place of the microphone in the telephone modulating circuit. This makes the signals on both wave lengths audible on non-regenerative receivers.

At ten A. M. ships' signals are sent from NAA on 498 meters. A 10-K.W. set sends C.W. on 2,650 meters, an Army Air Service set transmits on 1,500 meters, and the 1-K.W. telephone transmitter is used for speech broad-

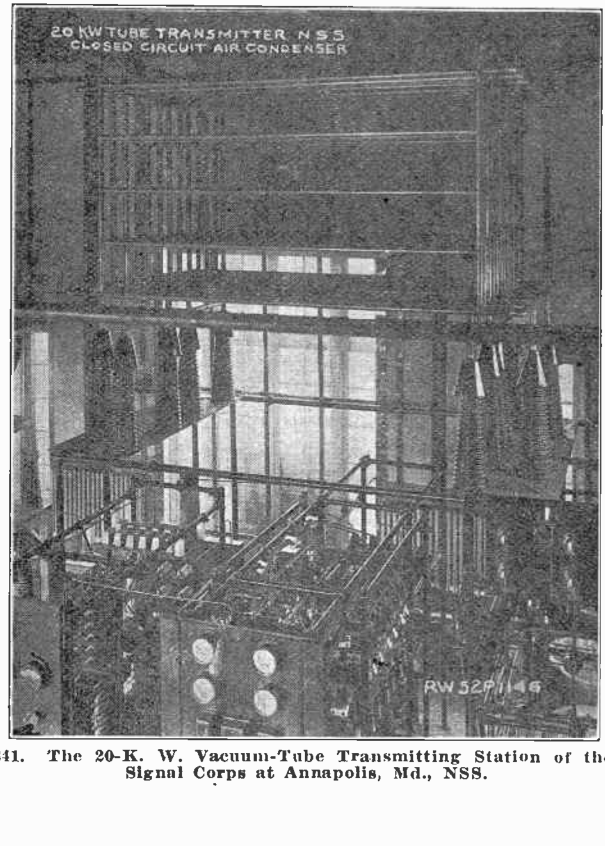


Fig. 341. The 20-K. W. Vacuum-Tube Transmitting Station of the U. S. Signal Corps at Annapolis, Md., NSS.

casting of weather reports and information given out by the Department of Agriculture.

The 20-K.W. station at Annapolis, which was built for the Navy and afterwards purchased by the Army, is illustrated in figures 341 and 342. Note the air dielectric condenser composed of brass pipes. This station obtains its power supply from the 25-cycle 6,600-volt power-line of the Washington, Baltimore and Annapolis Railway. It is reduced through a bank of three 25-Kva. delta connected transformers to 220 volts. This 220-volt supply is then stepped up by suitable transformers, rectified by twelve 2.5-K.W. Kenotrons, filtered by a combination of condensers and reactors, and delivered to the oscillator unit at 7,000 to 15,000 volts d.c. The oscillator unit consists of one 20-K.W. water-cooled tube. The cooling unit is composed of a motor pump and radiator, with the water piped through a flow indicator provided with a thermometer for visual indication of the temperature of the water. Electrical interlocks prevent operation of the tube without cooling, or with switches in wrong direction. The control unit consists of two 350-watt tubes with meters and controls for operation of either tube, and controls for two 150-volt Edison storage batteries. Keying is accomplished by control of the grid biasing voltage on the 250-watt tube, which is connected in the grid circuit of the 20-K.W. Tube. The keying system is entirely in duplicate to minimum chance for delay of traffic due to tube or relay trouble. A spare 20-K. W. oscillator tube is also installed ready for use in case of emergency. The circuit is an inductively coupled Hartley. The capacity of the brass tubing condenser is .002 mfd. This type of condenser eliminates chance of puncturing, which may occur with mica dielectric. A frequency-changer enables the operator to select one of five frequencies between 113 and 50.4 kilocycles, 2,600 to 6,000 meters. The entire equipment, with the exception of the antenna loading coil and variometer, is screened to assist in elimination of harmonics or other undesirable interference. The antenna consists of an 8-wire fan, 600 feet long, supported by a triatic between two 600-foot towers. The 8-wire fan is arranged in two groups of 4 wires to permit two separate leads to be brought in. By means of a switch these are tied together for connection to the transmitter; or, in the other position, they are connected to the armature of a d.c. generator to permit ice melting on the antenna.

Signals from the tube transmitter of the Signal Corps at NSS have been copied on the West Coast, in the Mediterranean and Alaska. The transmitter is worked by remote control from Signal Corps Headquarters in Washington, D. C.

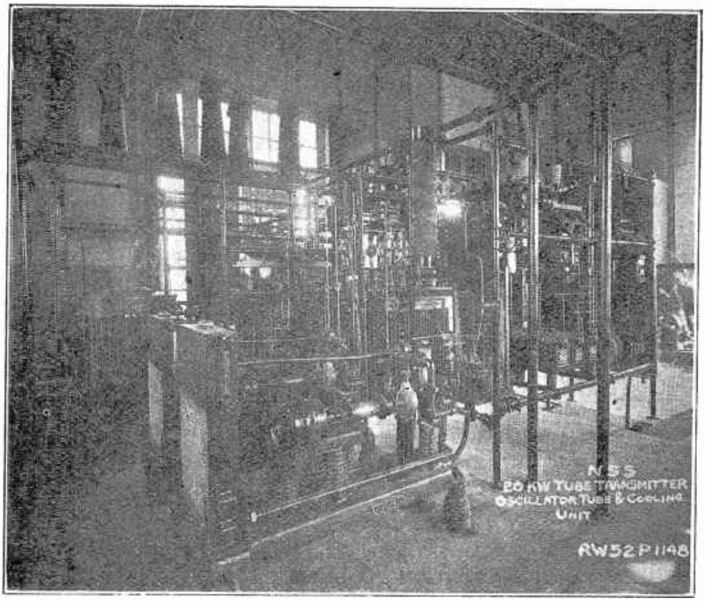


Fig. 342. Rear View of 20-K. W. Signal Corps Transmitter at NSS, Showing Duplicate 20-K. W. Tubes with Radiators.

The Army Radio Net, a map of which is included in the appendix, is busy day and night with government communication. This is conducted on both high and low wave lengths, a regular nightly schedule on short waves being kept up between Washington and San Francisco. The apparatus in the installations of the Signal Corps and the Navy is the best obtainable.

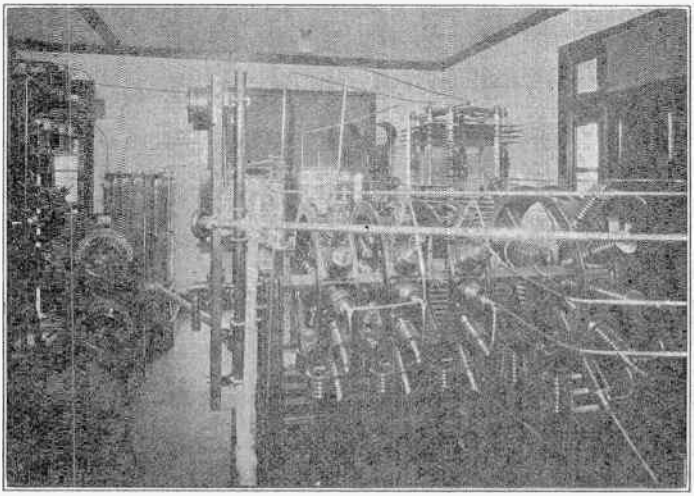


Fig. 343. 10-K. W. Tube Station of the U. S. Signal Corps at Fort Douglas, Utah—WVX.

(Observe the novel wave-length-changing switch in the foreground and the air condenser in the rear. A master-oscillator unit is at the left.)

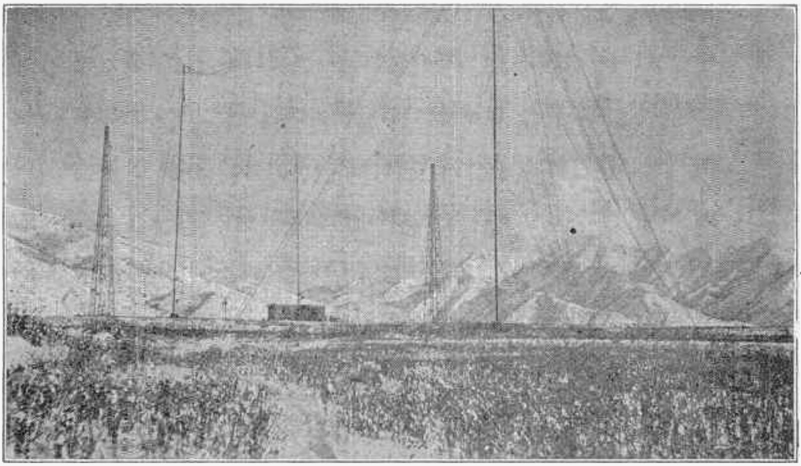


Fig. 344. Fort Douglas, Utah, WVX—An important Link in the Army Radio Net.

A wide variety of wave lengths is used by the different important stations, and communication is thus carried on with little trouble due to their interfering with each other. High-powered long-wave vacuum-tube transmitters are now in operation in many parts of the world. Frequently these stations employ an auxiliary short-wave system also.

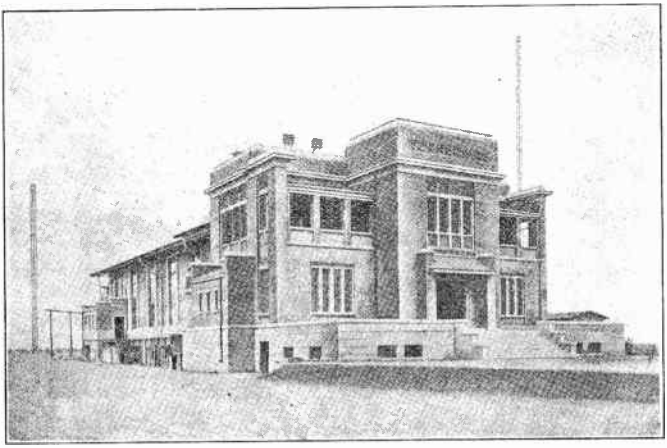
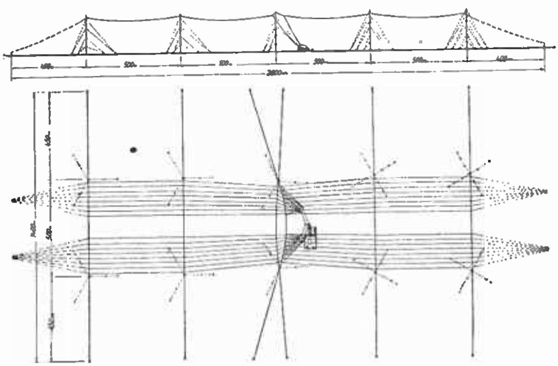


Fig. 345. A View of LPZ, the New High-Powered Transoceanic Radio Station, Monte Grande, Buenos Aires.
(Telefunken Zeitung.)



346a. Plan of the Masts and Antenna System at LPZ.
(Telefunken Zeitung.)

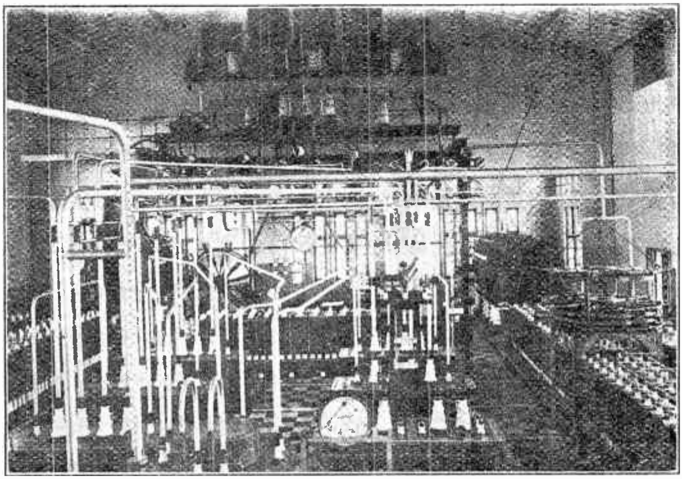


Fig. 346b. Interior View in the "Maschinenhaus" at LPZ. (Telefunken Zeitung.)

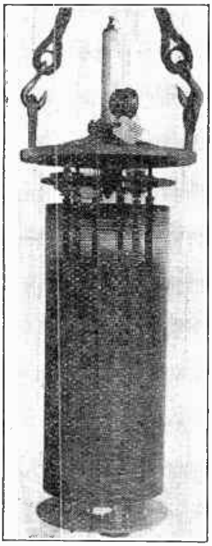


Fig. 347. Compressed-Air Condenser Removed from Case.

One of the most important of South American stations is LPZ of the Telefunken Company. This carries on communication with Europe on wave lengths of from 6,400 to 27,500 meters.

In several of the older high-powered long-wave stations huge compressed-air condensers were used, and these are often retained and still used for some purposes in connection with the high powered tube sets. A compressed-air condenser is merely an air condenser encased in an air-tight tank, into which compressed air is pumped to a pressure of about 350 pounds. A pressure gauge is mounted at the top.

LIST OF SHORT-WAVE STATIONS POPULAR THROUGHOUT THE WORLD.

(Radio Broadcast, April, 1926)

Call Signal.	Position.	Frequency in KC	Wave-length in meters.
POF	Nauen, Germany	22,209	13.5
2XS	Rocky Point, N. Y.	20,082	14.93
2XAW	Schenectady, N. Y.	19,988	15
2BR	Chelmsford, England	19,988	15
POF	Nauen, Germany	18,738	16
NKF	Anacostia, District of Columbia	18,738	16
2BR	Chelmsford, England	17,636	17
POF	Nauen, Germany	16,657	18
2XAD	Schenectady, N. Y.	14,991	20
KFVM	S. S. Idalia	14,991	20
POF	Nauen, Germany	14,991	20
NAL	Washington, District of Columbia	14,991	20
NEPQ	U. S. S. Relief	14,991	20
NKF	Anacostia, District of Columbia	14,414	20.8
WIK	New Brunswick, N. J.	13,628	22
2YT	Poldhu, England	11,993	25
POY	Nauen, Germany	11,993	25
FW	Sainte Assise, France	11,993	25
NKF	Anacostia, District of Columbia	11,758	25.5
AGA	Nauen, Germany	11,532	26
PCMM	Kootwijck, Holland	10,903	27.5
POW	Nauen, Germany	10,708	28
2XI	Schenectady, N. Y.	9,994	30
NAL	Washington, District of Columbia	9,798	30.6
2YT	Poldhu, England	9,369	32
ANE	Malabar, Java	9,369	32
NAJ	Great Lakes, Illinois	8,630	34
WQO	Rocky Point, New York	8,560	35.03
PCMM	Kootwijck, Holland	8,328	36
PCUU	Kootwijck, Holland	7,890	38
KFVM	S .S. Idalia	7,496	40
NAS	Pensacola, Florida	7,496	40
NAJ	Great Lakes, Illinois	7,496	40
NPG	San Francisco, Calif.	7,496	40
NRRL	U. S. S. Seattle	7,496	40
NOW	U. S. S. New Mexico	7,496	40
2XAC	Schenectady, N. Y.	7,496	40
NKF	Anacostia, District of Columbia	7,260	41.3
2XAF	WGY—Schenectady	7,160	41.88
5XH	New Orleans, La.	7,139	42
FW	Sainte Assise, France	7,139	42
WIZ	New Brunswick, N. J.	6,970	43.02
WQO	Rocky Point, New York	6,814	44
KZA	Los Angeles, Calif.	6,814	44
KZB	Los Angeles, Calif.	6,814	44
PCLL	Kootwijck, Holland	6,518	46
WHD	Sharon, Pa.	6,119	49
NPM	Honolulu, Hawaiian Territory	6,119	49
2XAD	Schenectady, N. Y.	5,996	50
SAJ	Karlsborg, Sweden	5,996	50

CHAPTER 35

The Radiotelephone

Fundamental Telephone Circuit—Microphone—Line-Telephone Modulation—Voice-Frequency Current—Carrier Wave—Absorption and Magnetic Modulation—Grid Modulation—Plate Modulation—Heising Modulation—Rectified a. c. Radiotelephone Supply—Resistance-Coupled Line Amplifier—Quartz-Crystal Control—Transformer Specifications—Airplane Telephone Transmitter—Airplane Antenna, etc.—Oscillograph—Monitor—Shielding to Prevent Harmonics—Glow Microphone—Land-Line Linked Broadcasting Stations—PBX—Repeating Station—Balanced Modulator—Homodyne Reception—Single-Side-Band Transmission—Multiplex Radiotelephony—Carrier-Wave Line Radiotelephony—Ten-Meter Beam Radiotelephony—Ten-Meter Receiver—Instructions for Operating Radiotelephone Transmitter—SOS—Licensed Operator on Duty at Broadcasting Station—Oratory and Radiotelephony—Radio Transmission of Pictures—Stations 3BSB, WRC, WBAP, 2XAR, WJZ, KPO, WEAF, WCAP, KDKA, KFKX, 2LO.

342. With the vacuum-tube transmitting circuits described in the preceding chapter, we have the basis of modern telephone broadcasting. Radiotelephony is a combination of the principles of vacuum-tube transmitters and land-line telephony. There is no definite boundary line between the interests of radio concerns engaged in telephone broadcasting and telephone companies. Radio companies are using telephone lines for long-distance relaying, and telephone companies have installed radio broadcasting stations. Telephone receivers and transmitters, with their appropriate circuits, including battery and coil, were appropriated by radio engineers; and vacuum tubes, "loud speakers," and amplifiers, originated by radio engineers, have been adopted, and in some cases greatly improved, by telephone engineers.

In the earliest days of telephony, the transmitter and receiver were practically the same in construction, but it was soon found that better results were obtained by employing instruments intended solely for transmitting, at the speaking end of the line. To distinguish it from the telephone receiver, this device is called a *microphone*. There are several types of microphones, the one most in use in this country on land lines being known as the "solid-back" microphone, on account of its construction. Its principle

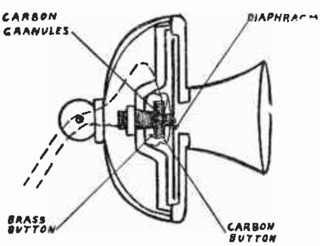


Fig. 348. Solid-Back Microphone.

is as follows: Imbedded in the heart of the microphone are two "buttons," one of solid carbon and the other of brass, or, in some makes, the buttons are both of carbon. These are called the electrodes of the microphone. Between the two electrodes is a space which contains some fine carbon granules, through which the current from a local battery must pass. The diaphragm is attached to the carbon button by means of a small pin.* When the vibrations of the speaker's voice, or other sounds, are impressed upon the diaphragm, causing it to vibrate with sound waves, the carbon button is mechanically forced to vibrate at the same rate. The resistance of the carbon granules, which form a great number of loose contacts, changes under the influence of every change in volume and pitch of the voice vibrations, and the local battery current is thereby changed into rising and falling current varying exactly in accordance with the inflections of the speaker's voice. This current is sufficiently undulating in character to be passed through a transformer, is, in fact, called a *"voice-frequency current"* by telephone engineers; and this composite electro-sound-wave vibration travels over the wire between the two parties in telephone communication, the original sounds being reproduced on the diaphragm of the receiving telephone. Of course, the *sounds* do not travel on the wire, that is, they are not *audible* until given an appropriate vehicle upon which to vibrate. But the *wave form* of the transmitted sound is conveyed along the wire by the battery current. In other words, the battery current is *modulated* into the wave shape of the sound waves. The reason that this cannot be used for radiotelephony is that the battery current cannot be radiated through space, but requires a material conductor. It is not intended to cover the subject of land-wire telephony here, but to simply give a brief elementary outline of it. From the first exceedingly simple systems, land-line telephony has developed so that the wiring diagrams of the usual city intercommunicating systems are wonderfully elaborate and

*The carbon-granule microphone was invented by Francis Blake, of the U. S. Coast Survey, in 1878.

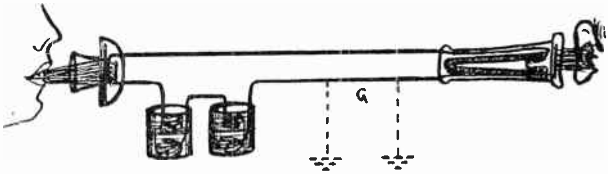


Fig. 349. Primitive Telephone Circuit.

intricate designs. Figure 349 illustrates the most primitive type of telephone circuit. It is workable, but, as can be seen, provides for only one-way conversation. The line may be cut at the points indicated at G and the two ends grounded, the earth forming part of the circuit. In figure 350, the fundamental principle of an intercommunicating system of the magneto type is illustrated. In this a magneto is installed for the subscriber to call with, and a local battery is employed to actuate the microphone. The magneto and ringer are connected in parallel across the line. This is sometimes referred to as a "bridging set" on this account. An automatic switching device, at S, disconnects the magneto from the line when it is not in use, and leaves the ringer across the line so that the station can be called by its bell. It also disconnects the ringer from the line when the magneto is in use. When the telephone receiver is in the hook switch the receiver is disconnected from the line and the microphone battery circuit is opened automatically. Taking the receiver off the hook closes these circuits, and two-way conversation is possible. Small signal lamps across the jacks connected to each line serve to notify the operator when the subscriber wishes to call some one, the current of the magneto lighting the lamp. When the operator inserts a plug into this jack the lamp is automatically cut out of the circuit. By putting another plug into the jack of the line with which the first subscriber wishes to communicate, ringing the magneto in the first station will

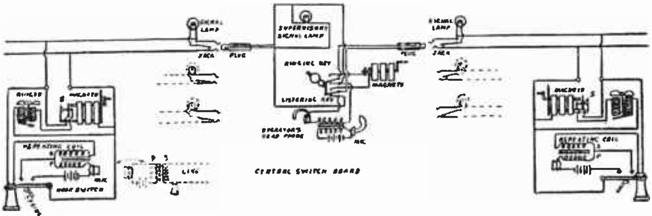


Fig. 350. Fundamental Principle of Two-Way Magneto-Type Telephone System.

operate the ringer in the second station, or the operator may call the second station from central. "Ringing off" is necessary with this type of station. This lights the supervisory lamp at central, and the plugs are removed from the jacks. In cities the batteries are usually installed at central, and the local apparatus is as shown in figure 351. A condenser is placed across the line in series with the ringer to prevent short-circuiting the d.c. battery supply. The line is then supplied with alternating current from an alternator, which is used to operate the ringer, and which is not stopped by the condenser. When the receiver is taken from the hook the primary of the transformer and the microphone are placed in series with each other across the d. c. supply line, and the fluctuations in this current caused by the speaker's voice actuate the diaphragm of the telephone receiver at a similar station somewhere else. The induction coil in this apparatus has generally a ratio of about 1 to 1, no step-up being used, as the battery voltage supplied from the central station is of much higher value than that employed in the local battery type of station.

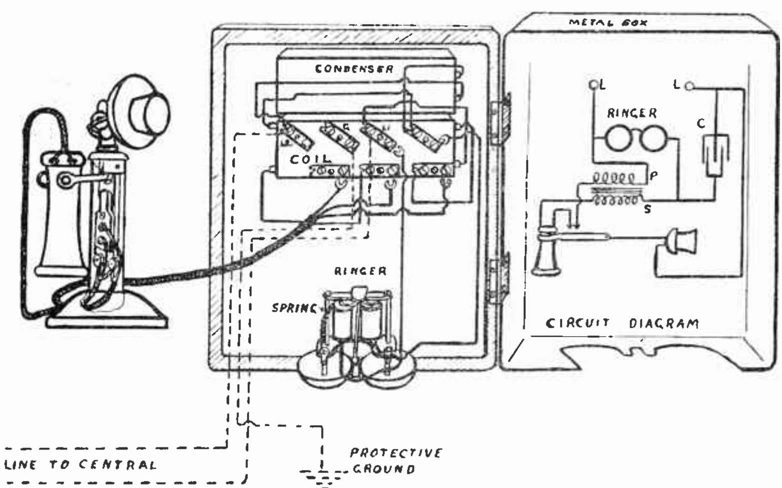


Fig. 351. Modern House or Office Telephone Installation, Employing Central Power System.

343. By using radio transmitting and receiving apparatus in place of the land wire, the microphone and telephone receiver function exactly as they do in line telephony. The

high-voltage high-frequency oscillations, or carrier waves, generated by the transmitter are *modulated* into the wave form impressed upon them through the microphone. As this wave form is of an audible frequency the sounds can be heard on a crystal detector. When conditions are most favorable for good modulation at the transmitting station and undistorted reproduction at the receiving station, the varying volume and timbre of the voice or musical instruments used at the transmitting station are as clear in the telephone receivers as if in an adjoining room. The modulating devices must be more carefully adjusted for the transmission of speech than is necessary for key transmission. The articulation must be preserved, and the quality of the voice or music must sound natural when reproduced in the receiver.

The simplest possible method of telephoning without connecting wires, and the earliest historically, is that of connecting the microphone directly in series with an antenna which is energized with high-frequency alternating current from either an arc or a high-frequency alternator. This

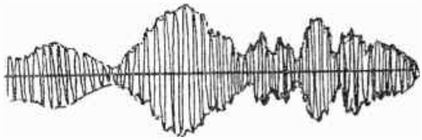


Fig. 352. Voice-Modulated Continuous Waves.

modulates the output by varying the resistance of the antenna. It is obviously suited for only low power, and the modulation is poor. In early experiments, to overcome heating of the microphones, when placed in the antenna circuit, several of them were often placed in parallel, resulting in distortion of the signals, on account of the diaphragms of the early microphones not having the same natural period of vibration. (In modern radiotelephone equipment several carefully calibrated microphones are frequently connected in parallel in the speech-input circuit.)

A different method is known as absorption modulation. It was used in many early experiments and for low-power amateur apparatus. In this, the amount of energy absorbed by the microphone circuit is in proportion to its resistance, and as the microphone resistance is varied by the sound waves impressed upon it, the absorption is varied, and hence there is a variation in the remaining energy which can be radiated from the antenna.

Two other methods of telephoning by use of modulating devices connected in the antenna circuit consist of the Fessenden detuning method, and the *ferromagnetic method.* The Fessenden method consists of the use of a fixed condenser in series in the antenna, around which is shunted a *condenser microphone.* This microphone contains no carbon granules, but depends for its operation upon the vibration of a number of movable plates—arranged alternately with a number of fixed plates. As the movable plates vary their proximity to the fixed plates, under the influence of sounds impressed upon them, hence the dielectric thickness of the air between the plates, the capacity of the antenna is varied and modulation takes place by detuning the antenna circuit. While this antenna series arrangement is no longer used in modern practical transmitters, a broadcasting microphone in which there are no carbon granules, but a device similar to a condenser, has been found by Marcus Hopkins, acoustic expert of Washington, D. C., to give modulation vastly superior to the carbon granule microphone. However, as moisture in the air decreases its dielectric strength, making it practically useless in damp weather, it can not be said to have reached a stage of dependability.

Ferromagnetic modulation is sometimes used by amateurs for low powered sets, and has been employed to a limited extent with the Alexanderson high powered alternator for long distance telephoning. The Alexanderson ferromagnetic method of modulation consists essentially of a means for varying the *inductance* of the antenna, and therefore constitutes a detuning type of modulation. In figure 354 the radio frequency is determined by the speed of the alternator, and the detuning of the antenna is solely of an audio frequency.

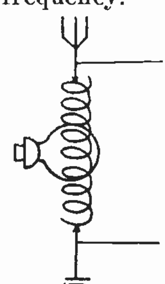


Fig. 353. Early Type of Absorption-Loop Modulation.

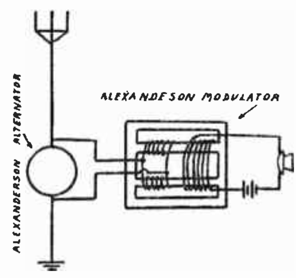


Fig. 354. Ferromagnetic Modulation of a High-Frequency Alternator Output.

344. While the methods of modulation described in the preceding paragraph differ somewhat in operation and results, they may nevertheless be classified under the general heading of *absorption* methods. Two other methods consist of modulating the radio-frequency output of the oscillator tube, by what is known as *grid modulation,* and modulating the *input* of the oscillator tube, known as *plate modulation*. *Grid modulation* is accomplished by substituting the secondary of a telephone transformer, or "repeating coil," for the grid-leak resistance, or of connecting it in series with the grid-leak resistance, as shown in figure 355. This may be applied to any of the transmitting circuits

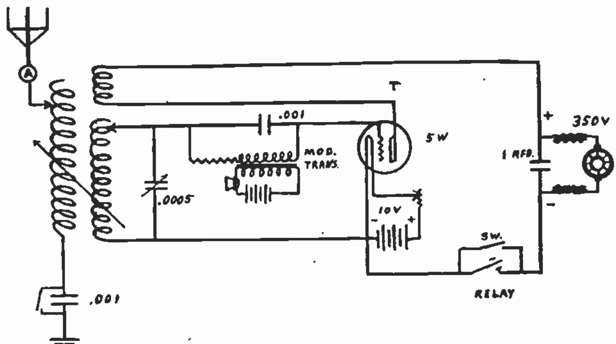


Fig. 355. Method of Connecting Microphone for Grid Modulation.

given in the preceding chapter, excepting those employing alternating-current modulation. Its principal advantage is economy, as it can be used with one tube, or two or three low-powered tubes, and does not require separate modulator tubes, as does the plate modulating system. Grid modulation is not suitable for high-powered transmitters, because with a high-power output of the oscillator, it is difficult to vary the grid voltage sufficiently to affect modulation. The operation depends upon the "biasing" of the grid voltage, under the influence of the voice-modulated battery current, which in turn controls the output of the tube with the familiar "trigger" action. In the operation of this arrangement, difficulty is often encountered by this grid bias reaching a point where it completely stops the antenna current at intervals during speech, and interferes with the transmission of articulation. This may generally be overcome by more careful adjustment. However, this method can never be expected to give as satisfactory results as plate modulation. The *modulation transformer,* as used in radiotelephony, has usually a high step-up ratio. For a 5-watt tube it may be constructed with about 220 turns of No. 24 silk-covered copper in the primary, and about 22,000 turns of No. 40 in the secondary. This is wound over an iron core, with the primary and secondary well insulated from each other. Some types are made with a closed laminated core, of which the

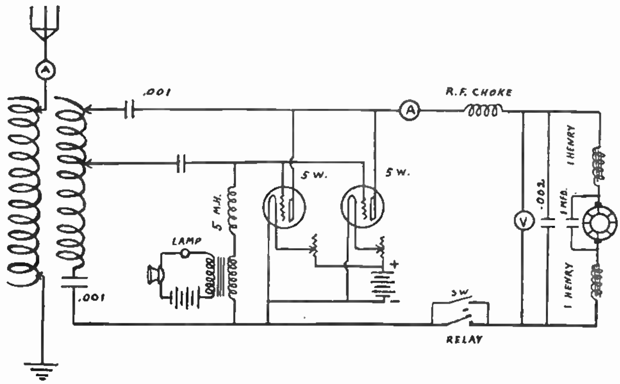


Fig. 356. Colpitts Circuit with Grid Modulation.

portion holding the windings is about 2½ inches long. Transformers for higher power are designed in proportion to the current to be passed through the windings.

345. *Plate modulation* is affected by varying the power *input* of the plate of the oscillator. This is much more efficient than any of the other methods previously described, and is employed extensively in the high powered broadcasting stations, and in the Navy and Signal Corps. In fact, it may be considered as the standardized method for all types of radiotelephones, except low-powered and inexpensive apparatus. This method was developed by Raymond A. Heising, of the Western Electric Company, and is generally known as *Heising modulation.* (For the development of this system, Mr. Heising had bestowed upon him the Morris Leibmann Memorial prize.) While successive patents for the Heising system of modulation have been granted, covering a period of several years, only the later forms of it will be given here, as it is these which are now in use.

As quoted in the preceding chapter, where the Heising system was shown for use with a key, A is a high-frequency generating system, and B a low-frequency generating system. For telephony additional elements are provided for the purpose of modulating the oscillations generated in system B, in accordance with speech or other sound waves. 15 is a low-frequency choke coil, and 16 is designed to offer a high impedence to the oscillations generated in system B. The modulator tube V, and generator tube G, are in parallel. Explaining the action of this system, Mr. Heising says: *"Variations of current in microphone circuit 17 vary the potential of the grid of tube V, which changes the impedence of tube V and causes corresponding changes of potential difference across tube G, whereby oscillations generated thereby are varied in amplitude."* Condenser 14 is to pre-

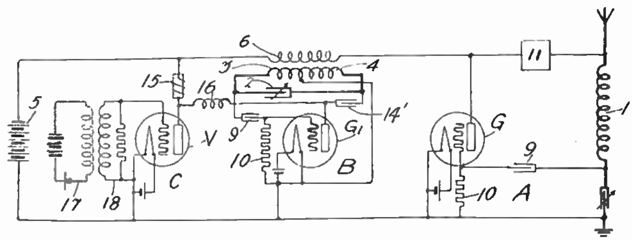


Fig. 357. Reproduction of Drawing from 1923 Patent for Heising "Carrier-Wave Signaling System."

vent short-circuiting of source 5, and also prevents speech-frequency variations in the anode, or positive electrode, of tube G. The coupling of coils 6 and 4 serves to impress the voltage generated by system B upon the anode-cathode circuit of A. 11 is a filter circuit, the use of which is optional. Coil 6 constitutes a high impedence for currents of the frequency generated in system A. In practice, the intermediate circuit B of the Heising patent specifications is often modified, or omitted altogether. In other cases one or more stages of audio-frequency power amplification are inserted between the microphone circuit and the modulator tube. In figure 358 is given a diagram of the standard Heising circuit. The choke coil of large inductance between the plate of the modulator and the source of power serves to keep the current constant, and to counterbalance any audio-frequency changes in impedence in the circuits supplied from it. On account of this the system is sometimes called a

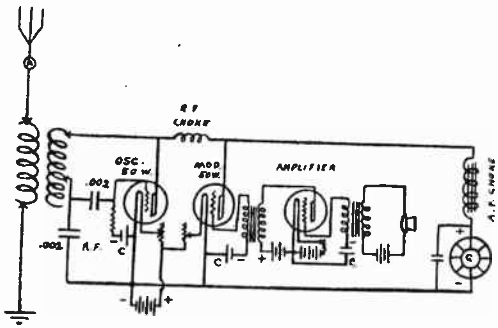


Fig. 358. Standard Heising Telephone System.

constant-current system. The modulator and generator tubes must be of exactly the same size and characteristics. Being connected in parallel across the circuit, any variation in the impedence of the modulator tube must vary the distribution of current between the two tubes, as the supply is kept constant. The *grid* of the *oscillator tube* functions solely in producing the radio-frequency oscillations of the carrier wave, and the grid of the *modulator tube* functions solely as an audio-frequency control of the plate current supplied to the oscillator.

Voice-frequency current from the microphone circuit increased in volume by the speech amplifier, and impressed upon the grid of the modulator tube through the modulation transformer, varies the voltage of the grid of the modulator tube. This varies the internal impedence of the modulator tube, and indirectly the plate voltage of that tube. This varies the impedence and plate voltage of the oscillator tube in inverse ratio, and the current passing through the audio-frequency choke coil is divided between the two paths, from filament to plate of modulator and oscillator tube, in proportion to their relative impedence and plate voltage.

The C batteries keep the grids of the tubes negative, for operating on the middle portion of their characteristic curves. This is necessary to prevent distortion of the speech-frequency wave. About 22 volts negative is required for a 5-watt tube, from 60 to 80 volts for a 50-watt tube, and in proportion for other tubes of higher power. In some cases a variable resistance is used in place of the C battery.

A special type of choke coil, having the iron core arranged as in figure 330b has been designed for this system of modulation. It is wound over a core of laminated silicon steel and has a small air gap on one side for the purpose of reducing losses from heat in the core. This coil is usually wound so as to have an impedence about double the effective resistance of the parallel oscillator and modulator. The radio-frequency choke coil prevents the high-frequency

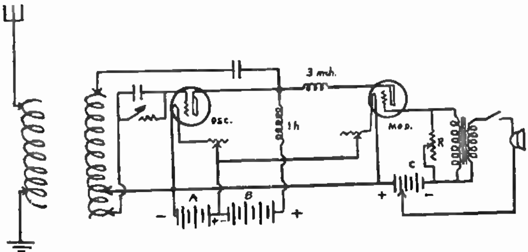


Fig. 359. Low-Powered Adaptation of Heising System.

oscillations generated by the oscillator circuit from flowing back through the modulator tube or generator windings. It has a low metallic resistance.

With this system, when favorably adjusted, it is possible to modulate the continuous oscillations from zero to twice their original value. Also, if the variations of grid voltage in the modulator tube are so strong as to completely stop the flow of current in the modulator tube, modulation will cease. This is referred to as "blocking" the modulator, or "over-modulation." In figure 356 a small glow-lamp is shown in series in the microphone circuit. A milliammeter may be used in the same place. This is a convenient method of checking the modulation. In figure 359 the microphone circuit is indicated as deriving its power from the same battery that is used for obtaining the grid bias. In this the resistance across the secondary of the modulation transformer, of 1 or 2 megohms, is for the purpose of reducing distortion by giving some control of the secondary voltage.

Figure 360 is a circuit diagram of a telephone transmitter employing two 5-watt oscillators, two 5-watt modulators, and four kenotron rectifiers. Factory-built transformers may be obtained, having separate secondaries for the plate and filament supply, and also another winding for use with kenotron rectifiers. They come in sizes appropriate for the power of the tubes with which they are to be used.

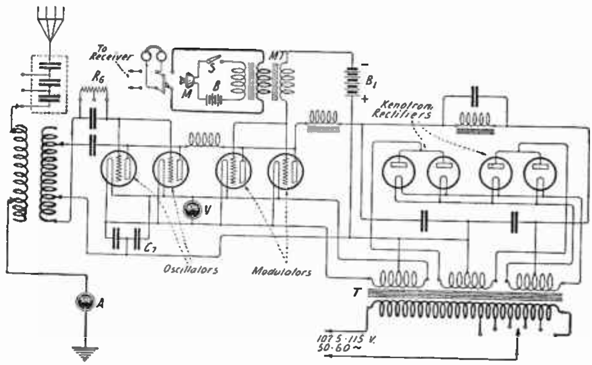


Fig. 360. Telephone Transmitter Employing Constant-Current Modulation. (Radio Corporation of America.)

Unrectified alternating current is not suitable for a power supply for radiotelephony. The modulation caused by the supply, as in figures 313 and 315, interferes with the modulation by speech or music. However, when properly rectified and smoothed out by efficient filtering systems, it is a convenient method of obtaining the necessary high voltage.

346. Figure 361 indicates the arrangement in use at station 3BSB, Washington, D. C. A quartz crystal, having a natural period of vibration of 2000 kilocycles, or 150-meter wave length, is used in connection with a 5-watt tube as a master oscillator. The output of this circuit is passed through a 100-watt power amplifier. The latter employs two 50-watt tubes in parallel. One of these 50-watt tubes is arranged with a switch so that it can be used as a modulator tube for the Heising method of radiotelephony when desired. When used for telephony, the 5-watt tube and quartz crystal are also in operation for producing the oscillations. A double-commutator generator is used for plate supply, providing 400 volts for the plate of the 5-watt tube, and 1000 volts for the 50-watt tubes, as shown in the drawing. The contacts to the C battery are variable, and in operation these are moved until the milliammeters indicate the desired plate current in each tube. This battery is used instead of a grid condenser and grid leak, and has been found to give better control. When the grid battery voltage is increased, the plate current is decreased, and vice versa.
The negative potential generally used on the grid of the

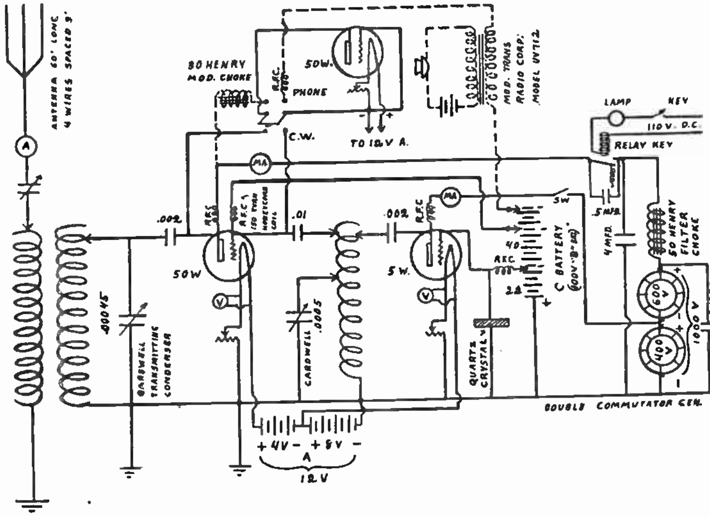


Fig. 361. Circuit Diagram of Amateur Station 3BSB.

50-watt tubes is 60 volts, and on the 5-watt tube 20 volts. When the coupling coil between the 5-watt tube and the power amplifier, and the .0005-mfd. variable condenser shunted around it, are tuned for a frequency just off of the natural period of the quartz crystal, the crystal will automatically start to oscillate, varying the potential of the grid of the 5-watt tube, and causing it to oscillate at a frequency controlled by the frequency of the crystal.

The modulation is not forced directly upon the grid of the low-powered tube, the grid of which is controlled by the quartz crystal, experience having shown that better results are obtained by using this crystal-controlled tube, as a master oscillator feeding into a higher powered system upon which the speech frequency is eventually impressed.

The radio-frequency choke coils in the grid and plate leads must be of the same frequency as the crystal, to prevent any feed-back or feed-ahead. A feed in either direction will either stop the oscillator or stop the control.

Station 3BSB has been heard in England and France, as well as in every state in the United States, and its many novel and modern features are worth duplicating.

347. Radiotelephony has developed along three different lines—airplane telephone apparatus, which was the first branch of this art to receive the attention of Government engineers—broadcasting stations, which are now disseminating entertainment, market reports, political campaign material, etc.—and commercial vacuum-tube telephone apparatus adapted for practical use in the commercial handling of telephone messages between seagoing vessels, and for interlinking the line-telephone systems with oceanic radiotelephony.

Two general methods of handling the antenna problem for airplanes have been developed. The trailing wire has proved the most efficient from the radio operating standpoint, but has possibilities of danger to the machine in case it becomes entangled in any of the working parts. The wire is wound on a reel located inside, or on the outside, of the fuselage, and can be unwound when desired. A weight at the end of the wire makes it feed out smoothly and keeps it straight and taut. The tube which the wire feeds through is called the "fairlead." The wire makes electrical contact to the radio apparatus by contact with the inside of this tube. The guy wires and metal parts of the plane are used for a counterpoise. Before landing the wire must be reeled in. In some cases the trailing wire is arranged as indicated by the dotted lines in figure 365. This is less dangerous in flying, and is not as directional as the longer single wire. However, being less directional and of shorter wire, its range towards a given point may be somewhat less. The other method is to erect a permanent and rigid network of wire over the top supports of the plane, using the stay wires, etc., as counterpoise, as usual. This is mechanically more desirable, but lacks the radiation of the trailing wire. It also increases the air resistance in flying. The length of the trailing wire determines the wave length radiated.

In airplane installations, many precautions are taken which are not necessary in most other cases. The different pieces of apparatus are usually mounted, or suspended, on springs which are used as shock absorbers. Vacuum-tube sockets are mounted on soft rubber cushions. Means are provided for locking the adjusting devices so that they can not rotate or slide out of position after tuning has been accomplished. Extra heavy insulation is used, and key contacts are enclosed in sheet-iron or gauze covers to prevent

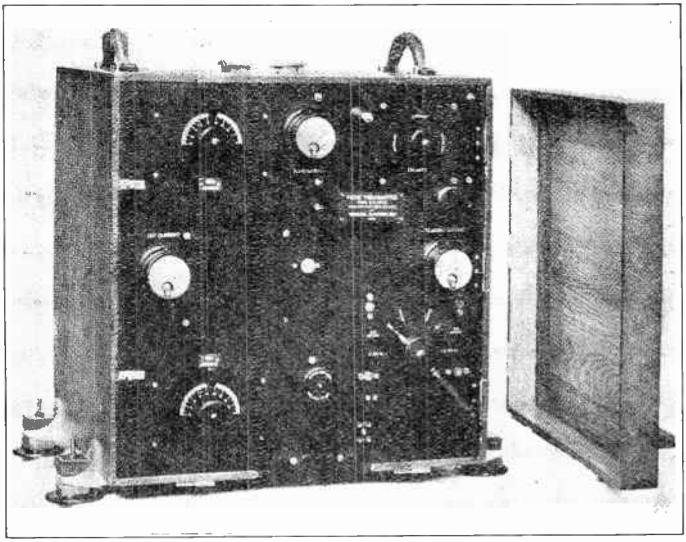


Fig. 362a. Typical Aircraft Radiotelephone Transmitter of the U. S. Navy. No. SE-1390.
(Proceedings of Institute of Radio Engineers.)

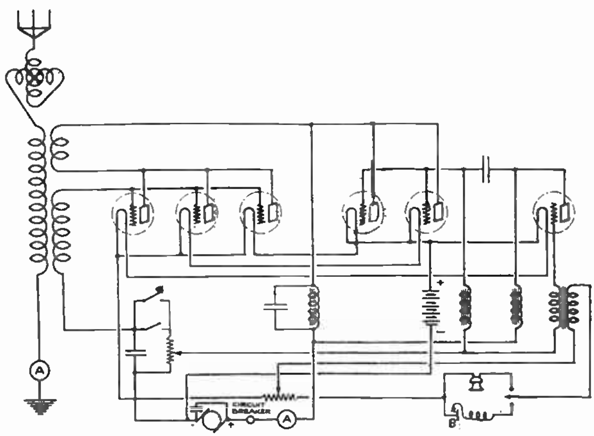


Fig. 362b. Wiring Diagram of SE-1390. (IRE.)

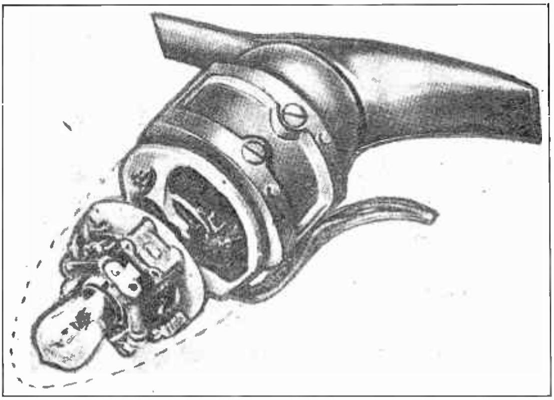


Fig. 363. Wind-Driven Generator for Airplanes, with Cap Removed.

Fig. 364. Aviator's Helmets with Head Phones.

the possibility of an electric arc igniting gasoline fumes, or setting fire to the inflammable type of varnish used on the wings and fuselage.

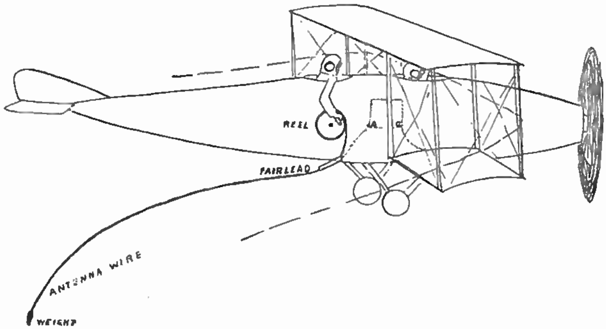


Fig. 365. Trailing Antenna Used with Airplanes.

348. The broadcasting stations are now a matter of general public interest and daily news. The Radio Corporation of America's station in Washington is known as WRC. Of this the owners say: "The location of the station is an exceptionally good one, at one of the highest points in the city, with no tall steel structures in close proximity to absorb and influence the waves radiated from the station. Placed diagonally on the roof of the building, 218 feet apart, are two imposing steel towers which support the antenna wires 150 feet above the street. These towers are a recent development in the design of such aerial structures. The three corners of the towers, instead of being straight from base to tip, curve inward, this being known as "vertical bridge" construction, which distributes the pull and bending strain of the wires equally to all parts of the towers, each of which is 115 feet high. One hundred feet from the roof are the cross arms, 36 feet long, to which the four spans of wire are attached. Each wire from cross arm to cross arm is broken up by insulators into three sections. The sections at either end, 49 feet in length, are merely supporting cables for the active center sections which are 120 feet in length. From the exact center of each of these four active lengths a wire drops to the roof below, where all are connected together to a heavy copper lead-in which connects with the transmitters. The office, studio and equipment are all on

the second floor of the building, and entrance is made from the hall into a reception room, where artists and speakers may wait before facing the microphone. Were it not for a two-door and vestibule approach, no one could enter the studio while broadcasting was in progress without admitting extraneous noises which would affect the microphone. But with this feature built in, the director may open the outside door, step into the vestibule and, carefully closing the door behind him, enter the studio by the second door without disturbing the program. Over the second door is a brightly lighted sign commanding silence. Within the studio the windows are draped with heavy hangings. A unique feature of the walls, which is not apparent while

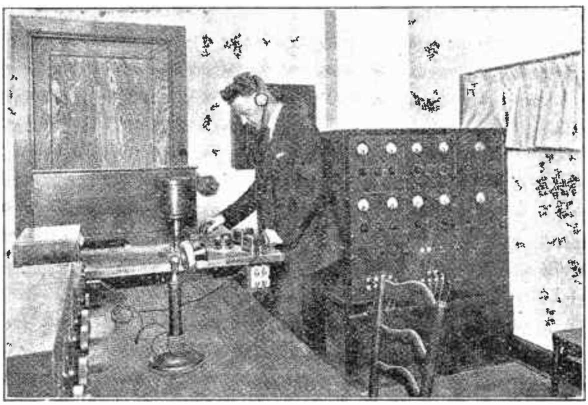


Fig. 366. Modulation Control Room of WRC, Showing Oscillograph at the right hand of the operator.

looking at them, is discovered when one touches the panels. A light pressure of the finger will bend them outward. These walls play an important part in broadcast transmission. They are made of wax-treated muslin laid over felt and absorb all sound waves not entering the microphone. This acoustically correct construction prevents even the minutest echo, which might otherwise blur the clearness necessary to enjoyable entertainment. On one side of the studio is a narrow curtained window beyond which is the voice control equipment. Here an expert operator is stationed at all times. Before him stands a large steel cabinet on the front of which are many knobs and meters. Through the window the operator can observe all that goes on within the studio and by means of the control apparatus within the cabinet maintain, at normal, the strength of the voice or music. Behind its black panel are vacuum tubes of medium size used to strengthen, or amplify, the electrical currents which carry the voice or music before actually reaching the transmitter. Its use is especially necessary when the program is being brought to the station over a wire a few miles in length. Used in connection with programs taking place in the studio, it is invaluable. The artist may move away from the microphone, may sway closer to it in his earnestness, but by a touch of a knob the man at the control board can offset these variations. Two transmitters, with 500 watts effective output, are installed. It is planned

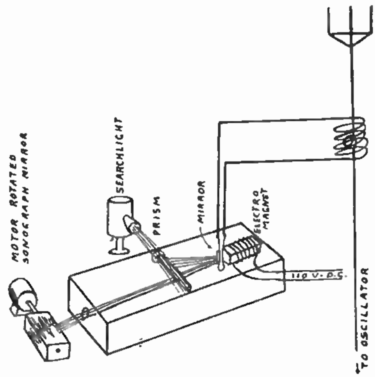


Fig. 367. Oscillograph at WRC.

to operate these alternately on alternate days, but the two sets may be combined for the broadcasting of some special event. Each is complete in itself and contains all necessary tubes, inductances, condensers and transformers, this equipment being mounted behind a large panel and completely shielded by a perforated steel cabinet, which not only eliminates any chance of interaction between the radio and audio-frequency currents, but protects the operators from accidentally coming in contact with bare surfaces carrying 2,000 volts. By means of an inter-communicating phone the operator may talk to the office, studio and reception room or be called by them. The motor-generators are housed in an adjoining sound-proof room, that their hum may not disturb either artists or operators. Two machines are provided, one for each transmitter. Each consists of a single motor driving two generators, one of which supplies 2,000 volts for the oscillator and modulator tubes, while the other furnishes 125 volts used to operate the automatic relays and the 88 volts which heat the filaments. An oscillograph further assures perfect transmission of programs. This may be switched into any one of the many circuits, and shows, by means of an undulating ever-varying beam of light, exactly how the artist's voice or music is affecting the electrical and radio currents. One knows instantly whether the sound waves are too weak, too great in volume or blurred. Because the law requires that a transmitting station must constantly listen in for distress

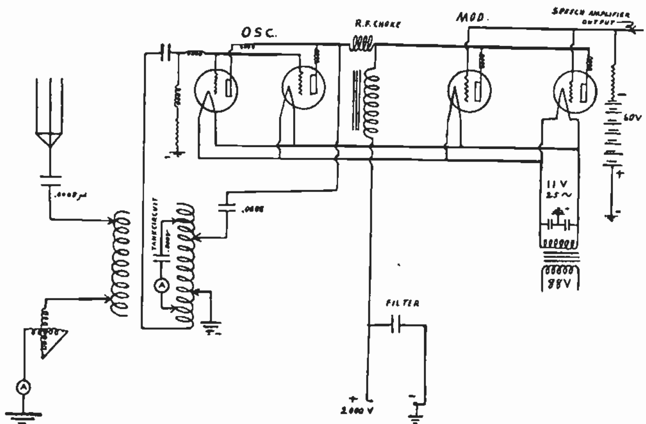


Fig. 368. Wiring Diagram of Transmitter at WRC.

signals from ships, a highly efficient receiver is provided." The oscillograph referred to is shown in figure 366, and its construction explained in figure 367. The radiated waves are picked up from the antenna circuit by means of a coil inductively coupled to that circuit. In series with this coil is a small loop to which is attached a mirror about three-eighths of an inch by one sixty-fourth of an inch in size. The small loop is placed in the field of a strong electromagnet; and as the strength of the radiated waves vary under the influence of the modulation, the relation between the magnetic field set up in the loop by this current and the field of the electromagnet causes the loop to turn, first one way and then the other, on the electrodynamic principle. To reduce damping of these oscillations of the mirror loop, the small loop and mirror are immersed in a jacket containing turpentine and castor oil. A strong light is thrown into the dark box in which the tiny mirror and electromagnet are enclosed, in such a way that it passes through a prism which deflects it at right angles onto the tiny oscil-

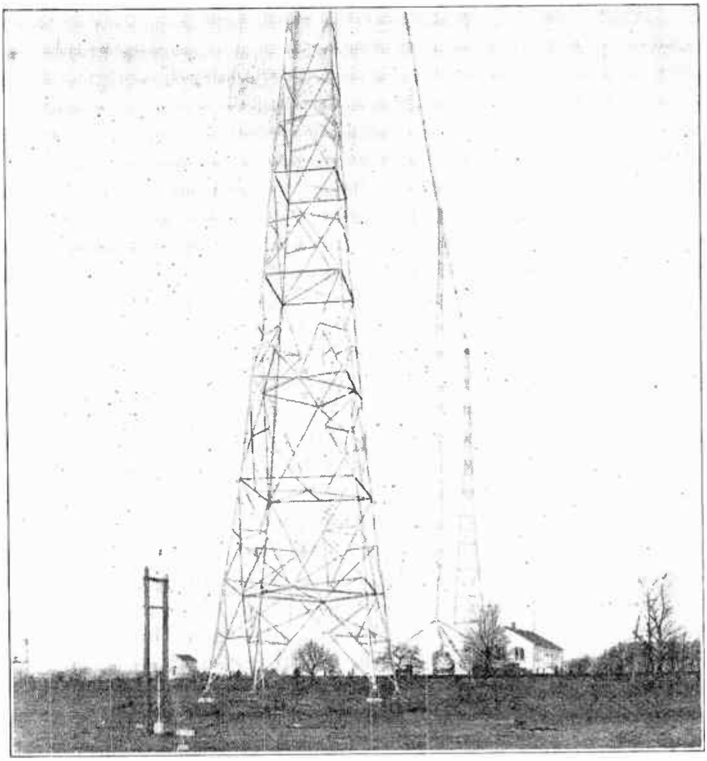


Fig. 369. Station 2XAR. (WJZ.)

lating mirror. The mirror then reflects the light beam onto a rectangular parallelopiped mirror which is rotated at high speed by a motor. The *actual waves* can be plainly seen with the naked eye on the rotating mirror. After a little experience with this arrangement, an operator can recognize any undesirable qualities in the modulation.

The transmitting circuit used at station WRC is an inductively coupled modified Hartley circuit, with some characteristics of the Meissner circuit. The shunted "tank circuit," shown in figure 368, was installed after the station was in operation, to reduce harmonics which were being radiated. The "grounds" in the modulator and oscillator circuits are attached to a common conductor. The greatest difficulty encountered in the early days of operating this station was induction of radio-frequency current back into

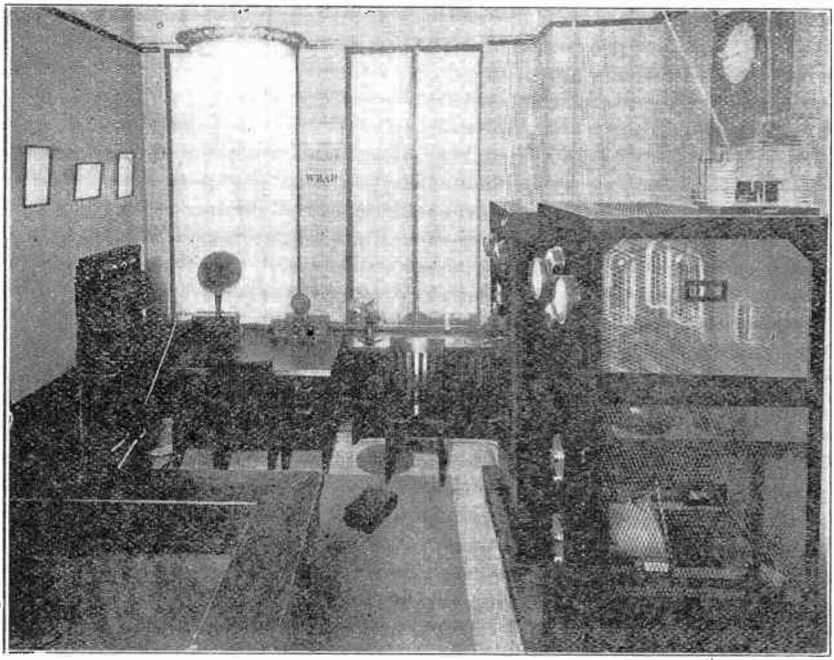


Fig. 370. Operating Room of the Broadcasting Station of the Fort Worth Star-Telegram, WBAP.

the audio-frequency circuit. All conductors in the low-frequency part of the apparatus are now shielded with lead cables which are grounded. A double-button microphone is used, that, is, one which makes a contact with the diaphragm in both directions.

The towers of the new high powered broadcasting and experimental station of the Radio Corporation of America, 2XAR, at Bound Brook, New Jersey, are shown in figure 369. This is the former station WJZ, which was situated on the roof of Aeolian Hall, in New York city. The photograph shows the transmitter house, sub-station, cooling tower and antenna tuning apparatus house.

The 300-foot steel towers of 2XAR become heavily charged with high-frequency current and, to prevent absorption, are well insulated from the earth. Markers visible by day, and red reflectors on which searchlight beams are directed at night, turn these towers from a menace into guide-posts for mail planes from Hadley Field near by.

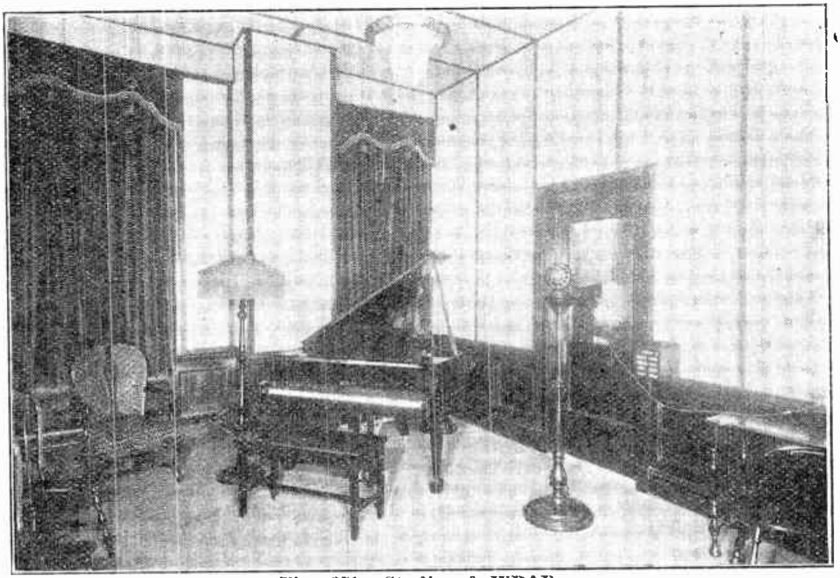


Fig. 371. Studio of WBAP.
(Microphone on tall pedestal in foreground.)

At Fort Worth, Texas, the Fort Worth Star-Telegram operates a broadcasting station known by the call letters WBAP. This is equipped with a Western Electric transmitter, with two 250-watt oscillators and two modulators of the same power. The antenna is a 4-wire inverted L, 100 feet long, with a 105-foot lead-in, and a maximum height of 180 feet. It is supported by steel towers on the roof of the Star-Telegram building.

349. The operation of the telephone broadcasting stations has awakened a renewed interest in the subject of acoustics, and in turn this has greatly improved the quality of the

broadcast programs over the early attempts. Important changes have been made in the microphones. Further development of the condenser microphone is under way. A "glow" microphone has been invented, so called because an electric discharge is *reflected* from a small disc of metal. The flame, or electric-discharge microphones, respond equally well to all pitches, which the older type of carbon device does not do. The microphone commonly employed in broadcasting today consists of a diaphragm of taut duralminum—the material from which dirigible bodies are made—with gold plating for contacts. No carbon is used. This has been developed from a stretched skin microphone invented by Emile Berliner, in Washington, D. C., about 1878.*

Fig. 372. Studio of KPO, of Hale Brothers' Department Store, San Francisco.

*See book, *Emile Berliner, Maker of the Microphone,* by Frederick William Wile, 1926. Also *Saturday Evening Post,* August 14, 1926, David Sarnoff.

A thick pad of felt is found to be an excellent support for the microphone, instead of the rigid supports frequently used. The microphone shown in figure 373 is in use at 2LO, the famous broadcasting station of the British Broadcasting Company, London.

Heavy draperies, as shown in figure 372, are often used in broadcasting studios to reduce reverberations.

350. The Chesapeake and Potomac Telephone Company for three years operated the broadcasting station WCAP in Washington, D. C. Due to rather complicated legal technicalities this popular and highly efficient station was closed and its call letters are no longer heard on the air. The transmitting apparatus was located in a room built on the roof of the telephone company's building and from this point Washington listeners heard simultaneously exactly the same program which was being broadcast from WEAF in New York, with which WCAP was connected by land wire. WCAP was also equipped with speech amplifiers, built into an automobile truck, and operated solely on storage-battery power. This was moved about the city to points connected with the main transmitting station by wire, and speeches, music, etc., broadcast from these different points through the main station, without requiring the presence of the performer at the studio. The transmitting circuit used at WCAP was designed by Mr. Colpitts of the Western Electric Company, and was a modification of the usual Colpitts circuit. Two 250-watt oscillators and modulators were used. The monitor system, used for checking the modulation, is illustrated in figure 374. A small flat pick-up coil was placed at the end of a solenoid in series with the antenna. The energy picked up by this coil was then used to operate a receiving tube, the plate and grid of which were tied together, making it virtually a two-electrode tube. Telephones were then plugged into this circuit, and a horn connected in the secondary of the transformer.

Fig. 373. Microphone Swung in Felt Support, as Used at 2LO.
(Courtesy New York Tribune.)

A number of milliammeters were used in this installation. One of these was in the output of the voice-frequency power-amplifier circuit; another, in the input circuit of the oscillator, served as an additional check on the modulation. A double-button carbon-granule microphone was used for ordinary occasions, but a condenser microphone employed when there was reason for unusual care in accurate reproduction, provided climatic conditions were favorable for its use. A balancing circuit, of inductance and capacity tuned to 5,000 cycles, was placed across the line connecting WCAP with WEAF, to counteract the effects of induction between the two long wires. The *static drain* shown in the accompanying diagram was added after the station had been in operation some time. It was for the purpose of conducting to the ground the static picked up by the transmitting antenna, and which interfered with the modulation, giving much the same type of noise as would have been caused by taking the grid leak out of the apparatus.

In the summer of 1926 WEAF passed into the control of the Radio Corporation of America, who continue to operate it under its well-known call letters. It functions, as previously, as a radio central, through which many programs are land-line delivered to various broadcasting stations

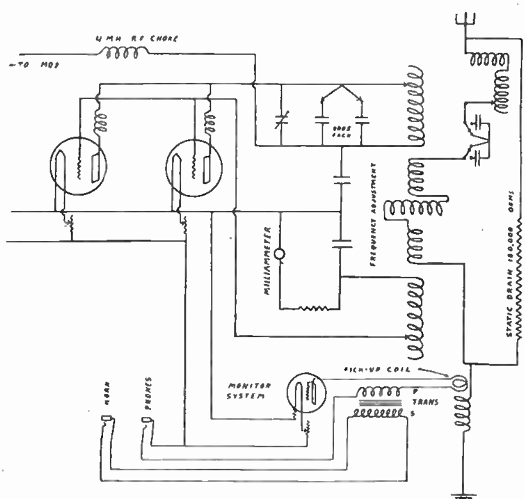


Fig. 374. High-Frequency Circuits of WCAP.

throughout the country. Bell telephone lines are leased for this purpose. In Washington the WEAF programs which were formerly sent out from WCAP are now broadcast by WRC.

Epochal history was made, in June, 1924, by station WEAF's broadcasting simultaneously *from over a dozen high-powered radio stations* the democratic convention in New York City. This was the first time that such a thing had been done, and it immediately opened vistas of the future radio service, in which millions of people would be enabled to hear what had previously been available to only a few. This was accomplished by the use of long-distance telephone lines between these stations and New York. An important feature of WEAF's installation is a regular PBX (private branch exchange) telephone switchboard, which is the terminus for several telephone lines connected with various micro-

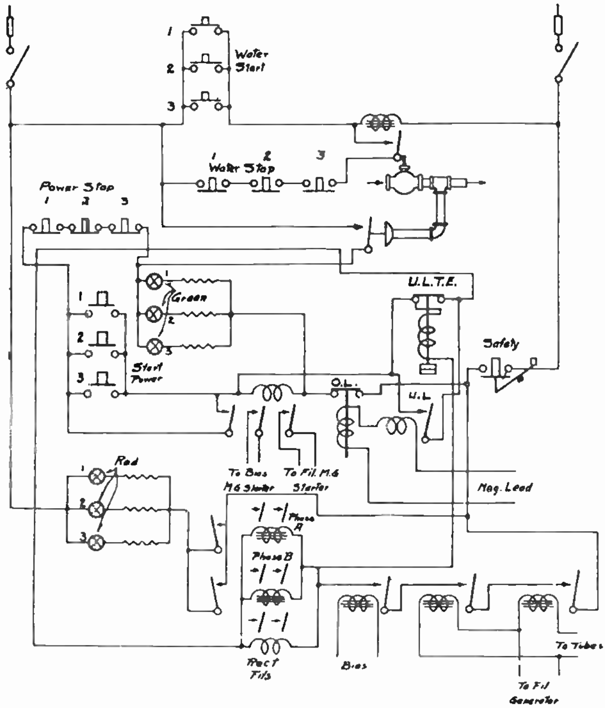
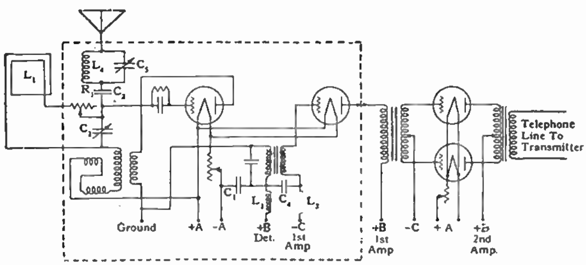


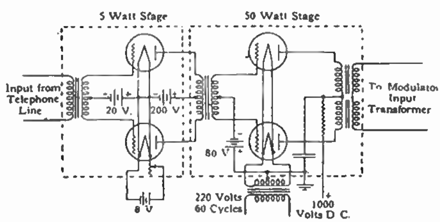
Fig. 375. Control System at KDKA.
(Courtesy of Proceedings of Institute of Radio Engineers.)

phones used for bringing in programs, and facilities for distributing these programs to different broadcasting stations. Similar interlinking lines are being installed by other stations. Referring to this movement, Dr. Alfred Goldsmith is quoted as saying: "The annual increase of listeners-in is numbered in the millions and, broadly speaking, the day is not far distant when the audience of linked chains of stations will literally be citizenry of the entire United States. The integrating effect on our population cannot be overestimated. That which links Mississippi to Illinois, and California to New Jersey, actually brings the people of the United States together in a great ethereal auditorium. *The radio wave therefore takes its place with the printing press as a major agency of civilization.*"

351. A different kind of relaying, or repeating, is that conducted between KDKA, well known station of the Westinghouse Company at Pittsburgh, Pa., and its branch station, KFKX, at Hastings, Nebraska. KDKA was the first of the great broadcasting stations, having been put into operation in the fall of 1920. The transmitter is automatically con-



HOOKUP OF RECEIVER AT HASTINGS.



STATION AMPLIFIER

Fig. 376a. Receiving Apparatus and Balanced Modulator Used at KFKX.

trolled from the operator's desk by push-buttons connecting with electro-magnetic relays, etc. Green signal lamps are lighted when the water pressure has reached normal, after which a push-button may be used to start the radio transmitter into operation. Red signal lamps indicate when the plate transformer primaries are connected to the supply.

A specially designed high-frequency transmitter is employed for the work with KFKX. The relaying between this station and the one in Nebraska is not accomplished by means of a land-line connection, as with the New York and Washington station of the Radio Corporation of America, and the Bell Telephone system. The signals radiated by KDKA are actually "picked up" by KFKX, amplified, and *retransmitted* at high power. *While the voice frequency, or characteristic wave form of the modulation is maintained throughout this performance, the frequency of the carrier wave is changed.* The program at KDKA is broadcast on two separate transmitters at the same time, one on the usual broadcast wave length, for listeners within range, and the other for KFKX on the higher frequency. The modulated high-frequency waves are passed through a receiving system at KFKX, used to operate a modulating circuit which in turn operates the oscillator at KFKX, and the program is then radiated on the broadcast wave length.

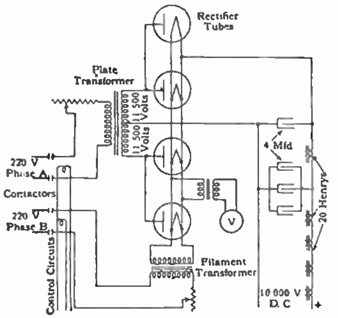


Fig. 376b. Rectifier and Filter at KFKX. (Radio Journal.)

Both transmitters are crystal controlled. The quartz crystal controls a 5-watt tube, which supplies grid excitation

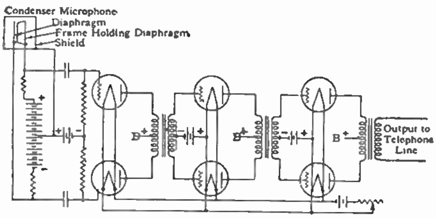


Fig. 377. Local Studio Balanced-Modulator Circuit of KFKX. (Radio Journal.)

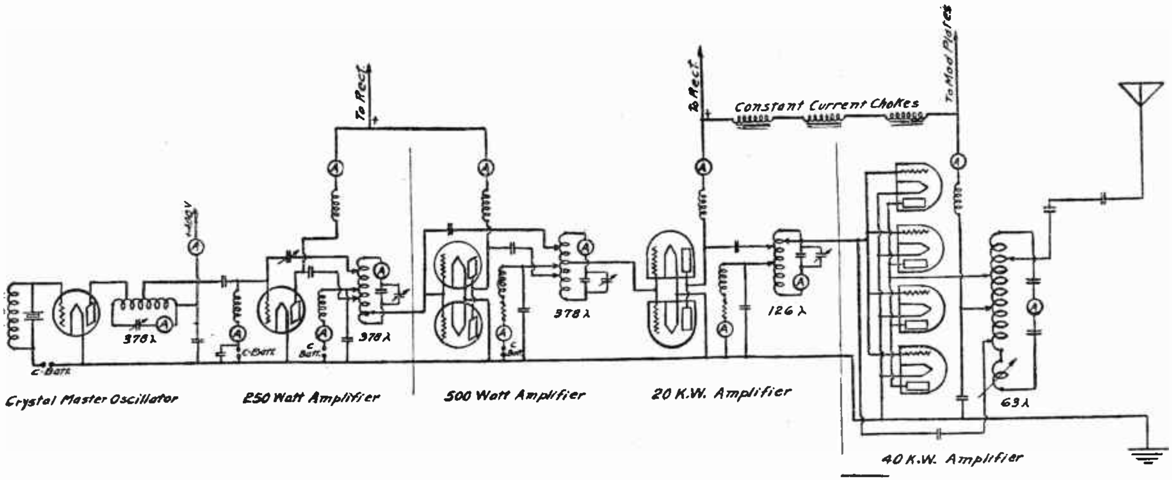
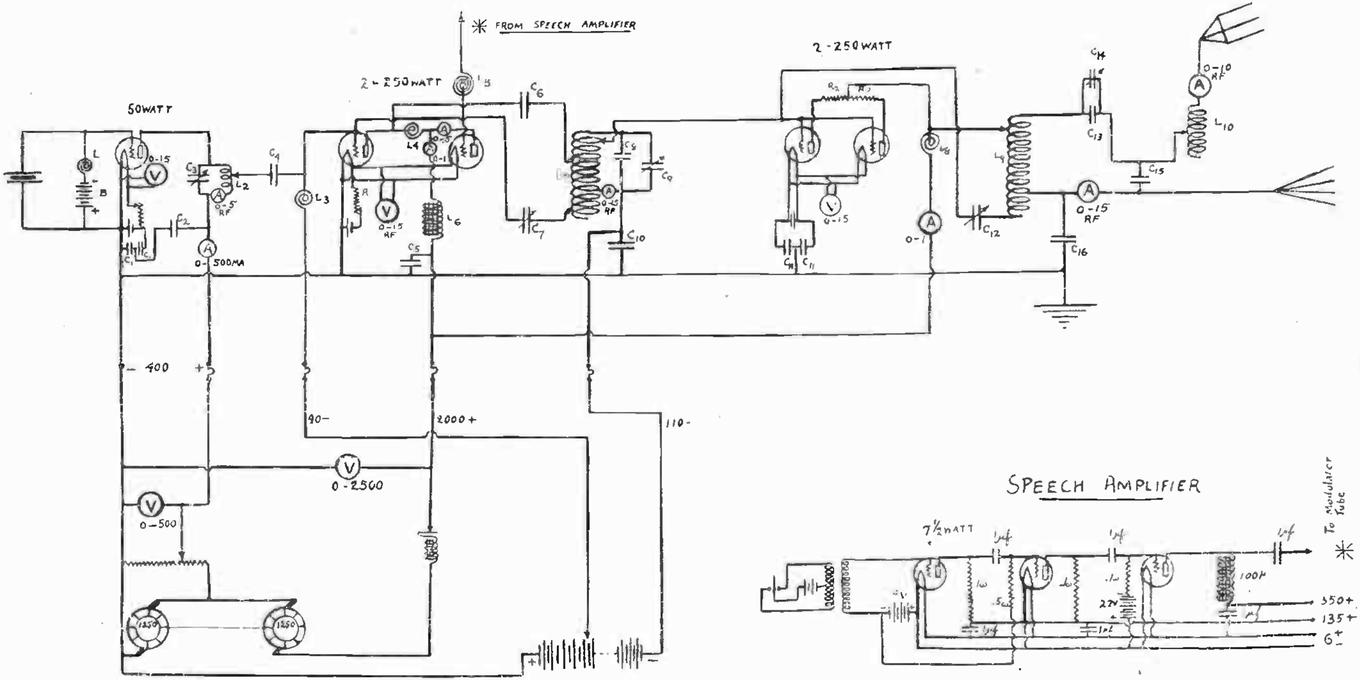


Fig. 378. Circuit Diagram of Crystal-Controlled Transmitter at KDKA.
(V. E. Trouant, Westinghouse Engineer, The Radio Home, April, 1926.)



Wiring Diagram and Specifications for a 500-Watt, 882 Kilocycle (340-meter), Crystal-controlled Radiotelephone Transmitter. Designed by A. Crosley, Radio Engineer of the Naval Research Laboratory, Bellevue, D. C., December, 1926.

KEY TO 340-METER CRYSTAL-CONTROLLED RADIOTELEPHONE TRANSMITTER

L —Choke coil (λ — 500).

B —36-48 volts.

L_2—Inductance 30 μh.

L_3—Choke coil (λ — 450).

L_4—Choke coil (λ — 450).

L_5—Choke coil (λ — 1000).

L_6—Choke coil 30 H.

L_7—Inductance 40 μh.

L_8—Choke coil (λ — 450).

L_9—Inductance 40 μh.

L_{10}—Inductance 60 μh.

R —1 Ω, 10 amps.

R_2—100-200 Ω, Vitrohm.

C_1—1 μfd., 200 volt, paper.

C_2—1 μfd., 1000 volt, paper.

C_3—.002 μfd., air.

C_4—.002 μfd., mica.

C_5—1 μfd., 3000 volts.

C_6—.002 μfd., mica, 2500 volts.

C_7—.0002 μfd., air.

C_8—.001 μfd., mica, 15 amps.

C_9—.0005 μfd., air.

C_{10}—1 μfd., 1000 volts.

C_{11}—1 μfd., 1000 volts.

V_{12}—.0002 μfd., air.

C_{13}—.001 μfd., mica, 15 amps.

C_{14}—.0005 μfd., air.

C_{15}—.02-.2 μfd., mica, tapped.

C_{16}—1 μfd., 1000 volts.

for two 250-watt tubes in parallel. These operate on 378 meters, the stages being neutralized against feed-backs. In each of the transmitters the arrangement is identical up to this point. In the 309-meter set, the glass 250-watt tubes excite the grids of the water-cooled power tubes. In the 63-meter transmitter, an intermediate stage is used, on account of the sixth harmonic of the 500-watt stage not being sufficiently pronounced to operate the power tubes. The frequency change is made in two steps. The glass tubes excite the grids of two power tubes having their plate circuits tuned for 126 meters. The output of this circuit is passed through a bank of four power tubes in which the plate circuit is tuned to 63 meters. The antenna is capacitively coupled to this tank.

352. The apparatus shown in figure 379 is a *line amplifier.* Its function is to build up the power of the microphone circuit for feeding it into the line, just as the usual speech amplifier is used for feeding directly into the transmitting apparatus.

Many broadcasting stations are now using resistance-coupled line amplifiers, as these produce no distortion (see paragraph 368). The amplifier shown in figure 379 employs Daven Resisto-Couplers. The coupling resistors have a resistance of about 70,000 ohms. The grid leaks taper from 2 megohms in the first stage down to 100,000 ohms in the last stage. UV-201-A or UX-201-A tubes are used throughout, with a plate voltage of about 150. The input transformer should be designed for the installation and varies with the characteristics of the microphone. The output transformer has a low ratio—about 2 to 1. This also is best designed for

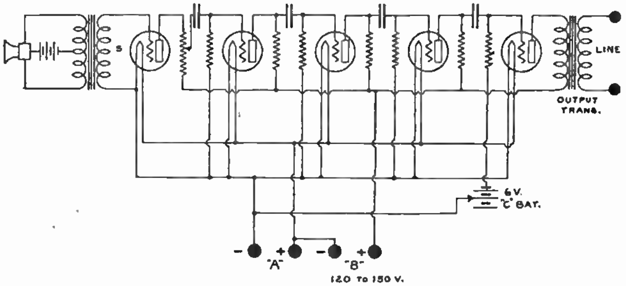


Fig. 379. Resistance-Coupled Line Amplifier Used in Radiotelephone Broadcasting.

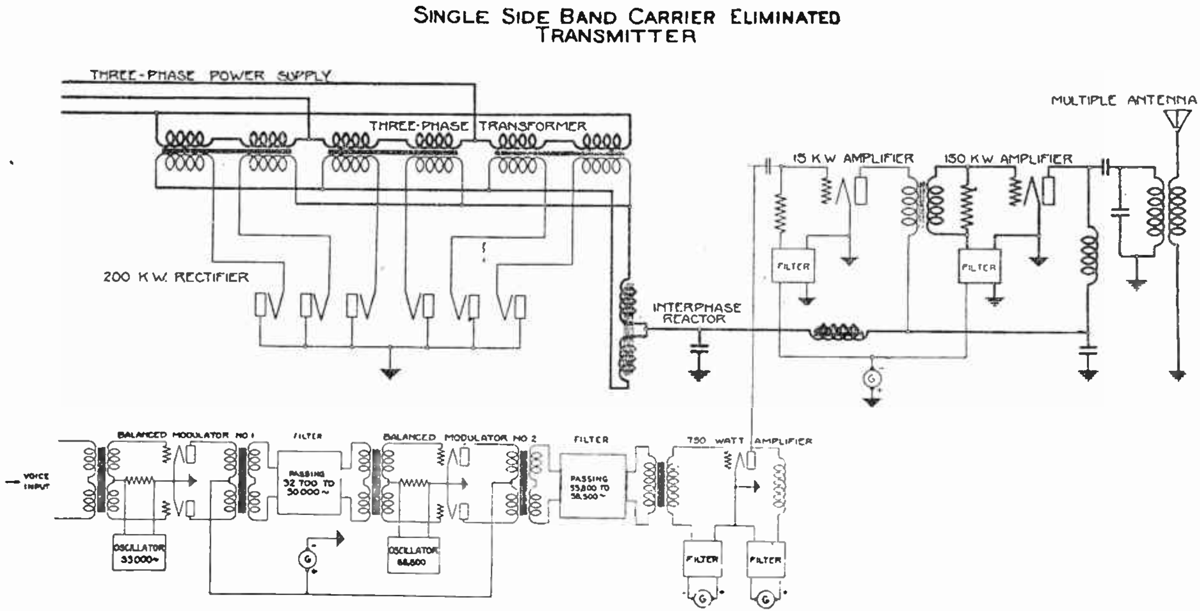


Fig. 380. Circuit Diagram of the Rocky Point Transatlantic Radiotelephone Station.
(Courtesy Bell Telephone System.)

the installation in which it is to be used. The capacity of the isolating condensers is .066 mfd.*

353. It was stated in paragraph 308 that the beat-note method of reception was not suited for radiotelephony. This is the case with the type of telephone transmission in general use. However, in some cases, by suppressing the side-band of waves either above or below the operating frequency, receiving methods are used which employ a local frequency. This is not the same as the heterodyne. It is sometimes referred to as "eliminating the carrier wave," and restoring it at the receiving station. This process consists of cutting off the side waves of one side of the modulation, including the carrier wave on that side. It is accomplished by the use of inductances, or inductance and capacity in parallel, and balanced modulating circuits. By the side-band is meant the band of waves of various lengths above and below the actual operating wave. Successful telephoning was accomplished during the summer of 1923 between Rocky Point, Long Island, and London, England, with a transmitter employing balanced modulators, with intermediate filter circuits. At the receiving station the side-band was restored to the signals by a locally generated current of exactly the same frequency as the transmitter carrier wave. This is called *homodyne* reception, in contrast to the heterodyne, being the same frequency instead of another frequency. The homodyne receiving system produces no audible beat, but simply makes intelligible the signals from which one side-band has been eliminated. Occupying a much narrower channel of wave lengths, it would be possible for several radiotelephones to be operating in this manner without interfering with each other. However, this system has not so far been found adaptable to short wave lengths, as it requires such accurate adjustment to obtain the frequency of the carrier wave to subtitute for the actual carrier wave, at the receiving station; and if this is not correct, the signals will be so distorted that the articulation is lost.

A discussion of the side-band carrier method, by L. Espenschied and H. D. Arnold, was published in the *Bell System Technical Journal* of October, 1923. This describes the tests made between London and the telephone station at Rocky Point, Long Island. Balanced modulators are used in this transmitter. "The result of this modulating

*For further information regarding resistance-coupled telephone line amplifiers, see *Proceedings of the Institute of Radio Engineers,* Vol. 12, No. 6.

action is to produce in the output circuit of modulator No. 1, modulated current representing the two side-bands; for example, the upper one extending from 33,300 to 36,000 cycles, and the lower one from 32,700 down to 30,000 cycles. These components are impressed upon a band filter circuit which selects the lower side-band to the exclusion of the upper one and of any remaining part of the carrier with the result that only one side-band is impressed upon the output of the second modulator. This second modulator is provided with an oscillator which supplies a carrier current of 88,500 cycles. The result of modulation between the single side-band and this carrier current is to produce a pair of side-bands which are widely separated in frequency, the upper one, representing the sum of the two frequencies, extending from 118,500 to 121,200 cycles and the lower one, representing the difference between the two frequencies, extending from 58,500 down to 55,800 cycles. In this second stage of modulation there is a relatively wide separation

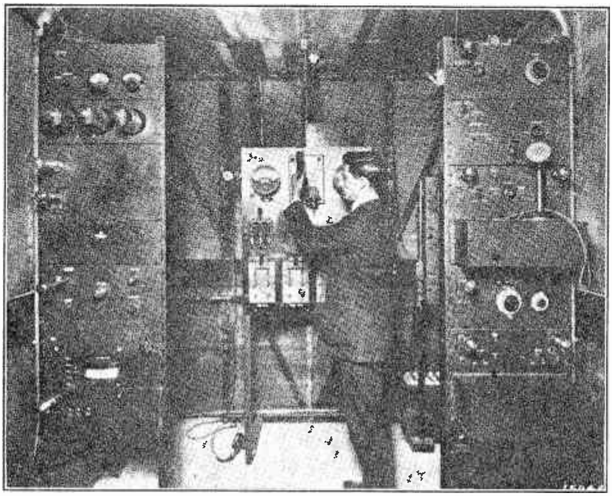


Fig. 381. Low-Powered Portion of the Rocky Point Telephone Station.
(Bell Telephone System.)

between the two side-bands which facilitates the selection at these higher frequencies of one side-band to the exclu-
allows a range of adjustment of the transmitted frequency
sion of the other. Another important advantage is that it
of the oscillator in the second step. In the present case, the frequency desired for transmission is that corresponding

to the lower side-band of the second modulator. The lower side-band of from 58,500 to 55,800 is, therefore, selected by means of the filter indicated. This filter excludes not only the other side-band but also any small residual of 90,000 cycle unmodulated carrier current which may get through the second modulator circuit if it is imperfectly balanced. Having prepared at low power the side-band currents of desired frequency it is necessary to amplify them to the required magnitude for application to the transmitting antenna. This amplification is carried out in three stages. The first stage increases the power to 750 watts. The amplifier employs in the last stage three glass vacuum tubes at 250 watts each and operating at 1,500 volts. The output of the 750-watt amplifier is applied to the input of the

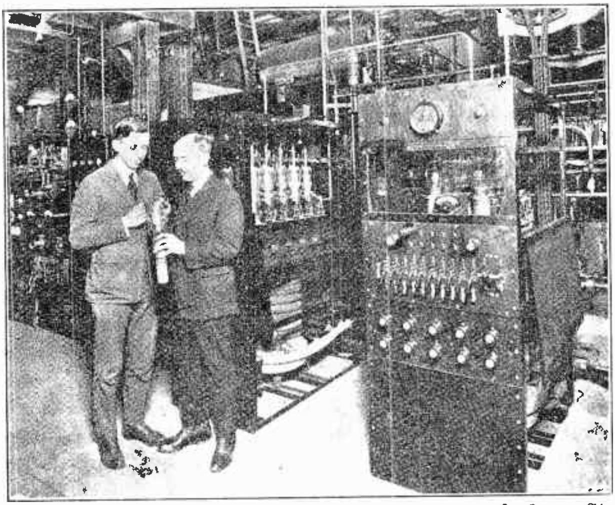


Fig. 382. High-Powered Apparatus at Rocky Point Telephone Station. (Bell Telephone System.)

larger-power amplifying system beginning with the 15-K. W. amplifier in figure (380). This consists of two water-cooled tubes in parallel, operating at approximately 10,000 volts. The output of this amplifier is applied by means of a transformer to the input of the 150-K. W. amplifier which consists of two units of ten water-cooled tubes each, all operating in parallel at about 10,000 volts" (from *Bell System Technical Journal*). The rectifying system shown at the left, in diagram 380, supplies d. c. current rated at 200 K. W. This rectifying system is operated from a three-phase supply, using 12 water-cooled tubes, two for each half of each phase. The plates are not attached directly to the earth, but to the neutral point in the supply line, making actually a portion of the circuit. The low-powered amplifier unit shown in figure 381 is completely enclosed in a shield

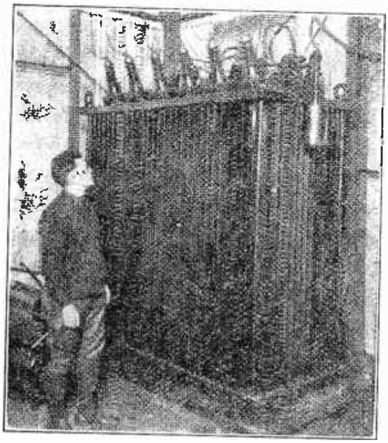


Fig. 383. 300-K. V. A. 60-Cycle, 3-Phase, 22,000-Volt, Oil-Cooled Transformer Used at the Rocky Point Transatlantic Telephone Station. (Western Electric Company.)

composed of copper wire. The arrangement used at the receiving station is indicated in figure 384. "The stepping-down action is accomplished by combining in the first detector the incoming band of 55,800 to 58,500 cycles with a locally generated current of about 90,000 cycles. In the output circuit of the detector the difference-frequency band of 34,200 to 31,500 cycles is selected by a band filter and passed through amplifiers and thence to the second detector. This detector is supplied with a carrier of 34,500 cycles which, upon "beating" with the selected band, gives in the output of the detector the original voice-frequency band. The object of thus stepping down the received frequency is to secure the combination of a high degree of selectivity with flexibility of tuning. The high selectivity is obtained by the use of a band filter."

354. *Commercial radiotelephone stations* are now becoming quite commonplace on the large *passenger liners.* The apparatus used for telephony on seagoing vessels follows the same general designs as similar transmitters on land, of

course avoiding unnecessary bulk. Carrying the linkage of the land-line telephone system and radiotelephony to communication with ships at sea, a historical test was made in the spring of 1920, when Mr. H. B. Thayer telephoned from his home in New Canaan, Connecticut, to the U. S. S. America, then 250 miles at sea, via the antenna at Deal Beach, New Jersey. From New Canaan to Deal Beach the communication was carried over land wire, where it was amplified, used to modulate the continuous-wave output of the oscillators, and then radiated from the antenna. The *Proceedings of the Institute of Radio Engineers,* June, 1923, contained an article by Mr. Lloyd Espenschied, of the Amer-

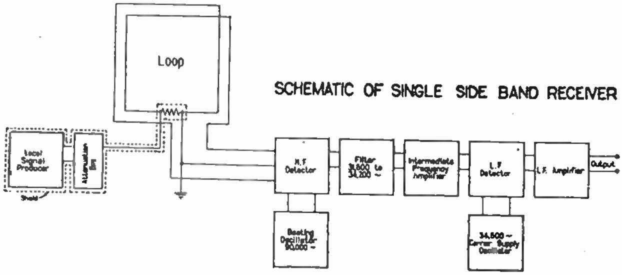


Fig. 7

Fig. 384. Side-Band Receiver.
(Bell Telephone System.)

ican Telephone Company, in which he relates the experiences of the experimenters who conducted the Deal Beach test. Mr. Espenschied says: "While the work was going on, a two-way telephone set for use aboard ships was developed, and in the spring of 1920 one of these sets was installed aboard the steamship Ontario, of the Merchants and Miners Transportation Company. Experimental communication with this ship by means of the model transmitters at both Deal Beach and Green Harbor, Mass., showed that commercial operation, at least for one channel, could be maintained. At the transmitting station the master oscillator, carefully shielded to maintain constant frequency, operates into a two-stage amplifier, the last stage being 50-watt tubes, and from there into a bank of six radio-frequency power tubes, each with a rating of 250 watts plate dissipation. Speech to modulate this radio-frequency output enters from a telephone line and is applied to a speech amplifier, the output of which operates into a bank of 250-watt modulator tubes in parallel. Thus both the radio-frequency and the speech-frequency currents are brought up to the high power level before modulation takes place. The six radio-frequency and six speech-frequency tubes have their plate circuits connected together and operate as a constant-current modulation system. At the receiving station (located about a mile north of the transmitting station) the incoming wave is impressed upon a loop antenna and the receiving set. The resulting detected output is then amplified and passed out on the telephone line. On the ship, separation of transmitting and receiving set is not practical and, as indicated above, takes place on the same antenna, so arranged that the receiving circuit offers high impedence to current of outgoing frequency and low impedence to incoming signals. The telephone switchboard (P. B. X., private branch exchange) is constructed to provide the necessary shielding, and to include telegraph, oscillator, coils, etc.

One operator located at the switchboard has complete control of the entire transmitting plane. The transmitters are tuned to 820,000 cycles, and the receivers to 739,000 cycles. *The greatest economy both in power and wave length range may be secured by transmitting only one side-band of the modulated wave. Moreover, this method has the great advantage that variations in the transmission characteristics of the medium do not cause as great fluctuation in the received signal. This is because the receiver signal is proportional to the product of the carrier and side-bands, and if the carrier is supplied locally instead of being transmitted, it is not affected by transmission factors.* This throws the burden of supplying constant oscillator frequency upon the receiver, and would defeat inter-communication with ships in emergency. These decisions, therefore, determined the general type of system to be used; namely, one in which many of the known advantages of single-band transmission were sacrificed in order to secure simple apparatus, to make use of the existing power tubes, and enable transmission to be received generally." Further discussing the problems of radio extension of the telephone systems to ships at sea, Mr. Espenschied sums them up as follows:

"(1) A much greater variability in the transmission equivalent to be expected in the radio link.

(2) A much greater and more variable interference, both natural and artificial.

(3) Lack of secrecy, in the sense of the wire system.

(4) Greater possibilities of cross talk between channels because of the use of a single medium.

(5) More complication in the matter of signaling and in setting up of the telephone circuit."

Telephone extension by radio is not confined to communicating with ships at sea. There is now in operation a regular toll service between Santa Catalina Island and Long Beach, California, 30 miles distant on the mainland. Regular telephone service is maintained by this system, between private telephones installed in homes and business offices on the mainland, and those on the island. The messages are handled through a regular telephone exchange, connected to the subscribers' telephones by the usual land wires.

355. As *multiplex* telegraphy and telephony have been achieved on land-wire systems, it is the dream of radio engineers to apply this same principle to radio transmission. A vast amount of research has been carried on with this in view, and a few patents have been granted. However, while it has proved workable, under test conditions, multiplex radiotelephony has not, at the time of publishing this book, found practical application in commercial work, due to the many complicated problems connected with this form of communication. Among the multiplex systems which have been patented are those of R. A. Heising, L. Espenschied and J. H. Hammond, Jr. The Heising system is an extension of his modulation system into the multiplex field. When used for multiplex, two or more modulating circuits are used, these being tuned to different frequencies. The multiplex system invented by Mr. Espenschied is designed for securing selectivity between a plurality of signals, with means for determining the signaling channels at either transmitting or receiving station, or both. The multiplex channels are collected at the sending station and separated at the receiving station at low frequencies. Of this, Mr. Espenschied says: "The essential principle underlying this method is that of a frequency step-up and a frequency step-down of a plurality of channels in common, in accord-

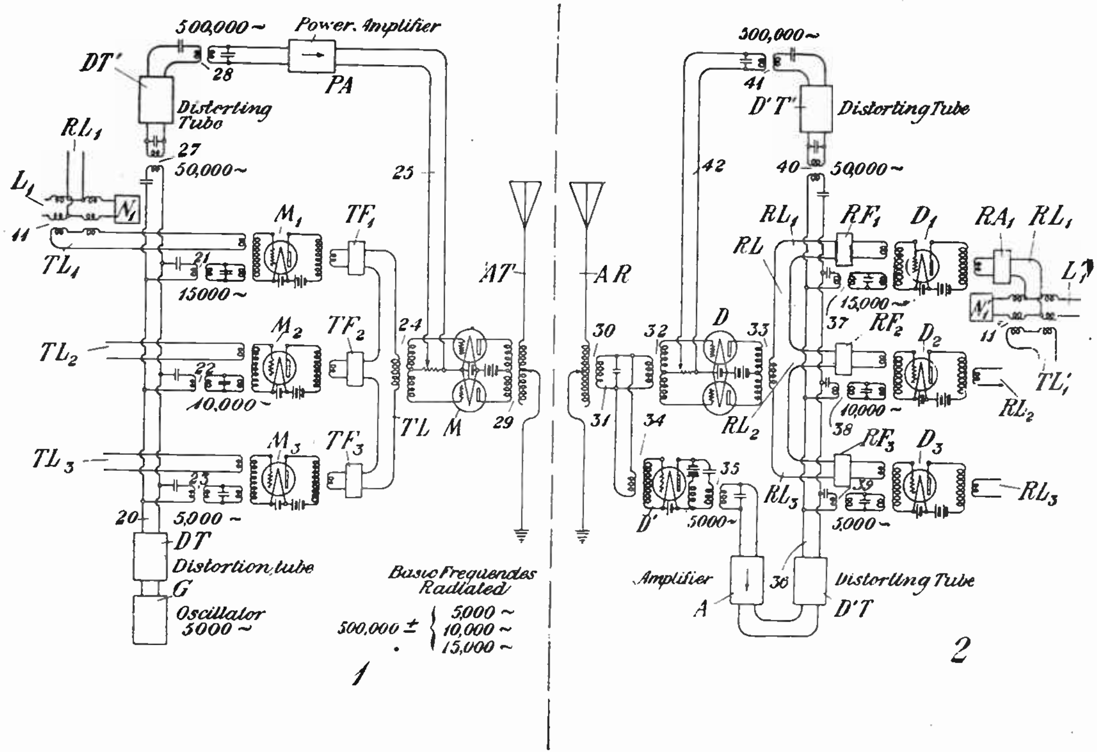


Fig. 385. Espenschied Multiplex Radiotelephone System.

ance with addition and subtraction of frequencies by modulation. This involves at least two stages of modulation. Signaling currents of each of the multiplex circuits entering into the system are impressed upon the carrier currents of intermediate frequency and these carrier currents are collected upon a common circuit at this intermediate frequency. The frequency of the group is then stepped up to the transmission frequency by modulation with a carrier of the desired frequency. At the receiving end the process is reversed, the frequency being stepped down to the intermediate frequency level by subtracting the original radio frequency and the superposed channels are then separated by suitable selective circuits at the receiving frequency. Each channel is then detected individually and becomes a circuit of ordinary signaling frequency. *Specifically it is proposed to generate at the sending station a fundamental frequency and produce harmonics of this fundamental frequency. The lower harmonics are then used as carriers for the first step of modulation and a higher harmonic is used as the carrier for the second step of modulation.* At the receiving station, a fundamental frequency may be independently generated and harmonics produced from this fundamental, one of the higher harmonics being used for the final step of frequency translation. An alternate expedient is to detect from the received band of frequencies the fundamental frequency generated at the sending station and produce from this frequency harmonics which may be used in the steps of modulation." In figure 385, the transmitting apparatus is indicated at 1, and the receiving apparatus at 2. TF and RF indicate frequency filters, TL transmitting channels, and RL receiving channels.*

356. Another dream of the engineers, which is finding practical application, is the *line radio,* or *"wired wireless,"* sometimes called *"carrier-current telephony."* This originated in the U. S. Signal Corps, with General Squier. The comparatively simple arrangement used for this is that of coupling the antenna connections of transmitter and receiver to a land line, which may be of practically any length. As a rule, the distance between the stations is increased many times by this method. The usual carrier wave is generated, and modulated, and then *conducted* in the direction

*For land-line multiplex and the use of the "phantom circuit," see book, *Telephone Apparatus,* by G. D. Shepardson.

of the receiving station along the wire. The line acts as a *guide* to the modulated radio waves, which presumably do not travel on the wire but in its immediate vicinity. The signals can be amplified at the receiving station, and finally made audible through a "loud speaker," in a manner not possible with ordinary land-line telephone conversation lacking the carrier-wave frequency. Communication can be carried on duplex, and the receiving apparatus may be provided with bells, operated by magnetic relays, which will ring when the circuit is energized by current of the frequency for which it is tuned. It is not necessary that the wires employed be those of a telephone system. Successful transmission has been accomplished over high-power lines. Where power lines are used connection cannot be made

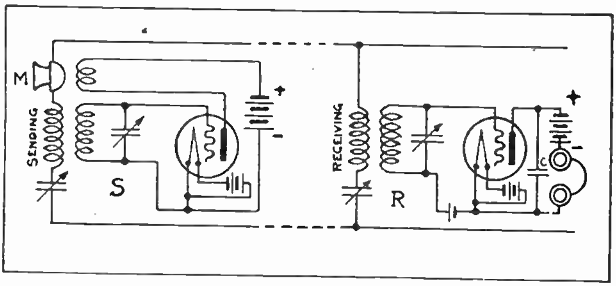


Fig. 386. Line Radiotelephone Circuit.
(From U. S. Signal Corps Radio Communication, Pamphlet No. 41.)

directly to the lines in any way, and the messages are conveyed to the power line by induction only, usually accomplished by running the antenna wires parallel to the power lines in proximity to them. Between the power house at Pit River, California, and its substation 200 miles away, regular telephone service is maintained by the use of the carrier wave over the intervening miles of their 220,000 volt transmission line. The antenna is a single wire 1,800 feet long, parallel to and about 10 feet from the power line. The ground connection of the radio apparatus is arranged as usual in ordinary radiotelephony. A wave length of about 10,000 meters is used, the telephone apparatus consisting of the usual type of radio transmitter, utilizing four 250-watt tubes, two for oscillators and two for modulators. At the receiving station a loud speaker is arranged so that it will roar when the calling circuit is closed.

357. Among the important developments in modern radio communication is that of directional transmitting on extremely short wave lengths. In Europe, Marconi has conducted considerable research along this line, proving that

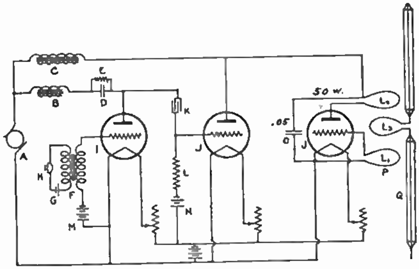


Fig. 387. Circuit for the 10-Meter Radiotelephone Transmitter.
(Bureau of Standards.)

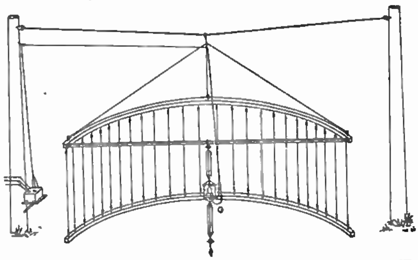


Fig. 388. Parabolic Reflector of 10-Meter Directive Transmitter.
(Bureau of Standards.)

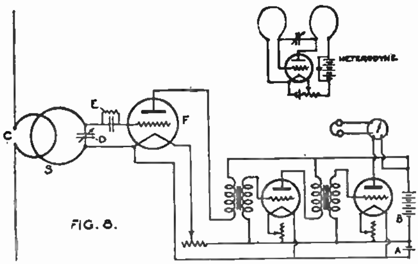


Fig. 389. Diagram of 10-Meter Receiving Set Used in Tests of Parabolic Reflector.
(Bureau of Standards.)

directional antennæ can be used advantageously for point to point communication, and that with short wave lengths great distances can be covered on low-power input, and with minimum interference. Experiments applying this principle have been conducted at the Bureau of Standards, Washington, D. C., by Messrs. Francis W. Dunmore and Francis H. Engle, with promising results. A 50-watt oscillator was used. The antenna system consisted of two short vertical cages, one placed above and the other below the transmitter. A coupling coil was aranged between the two vertical conductors, by means of which the transmitting circuit was coupled to the antenna. The generating set, with the vertical cage conductors, was suspended in the focal axis of a parabolic reflector. *Each wire of this reflector was separately tuned to exactly 10 meters* by adjusting its length. This turned out to be about 14 feet and 5 inches. Since the waves are reflected and radiated in one direction, a less powerful apparatus is required for transmitting a given distance than when a non-directive antenna is used. The internal capacity of the tube determines the upper limits of the frequencies obtainable; and it is obvious that all leads must be kept as short as possible. The plate and grid coupling coils consisted of a single turn each, 17 cm. in diameter. The antenna coil also was of the same dimensions. The two vertical sections of the antenna consisted each of six parallel wires 1.8 m. in length, arranged in a circle, and spaced 3 cm. apart. The reflector consisted of 40 wires, fastened to a frame constructed in the form of a parabola and spaced 30.47 cm.

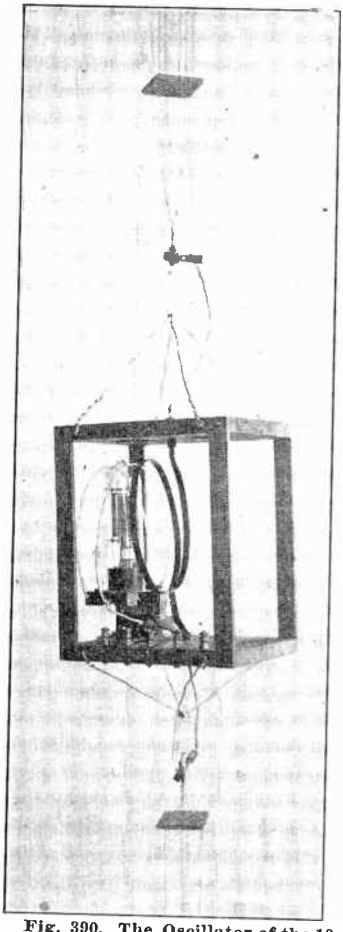


Fig. 390. The Oscillator of the 10-Meter Telephone Transmitter Suspended Between Two Vertical Conductors.
(Bureau of Standards.)

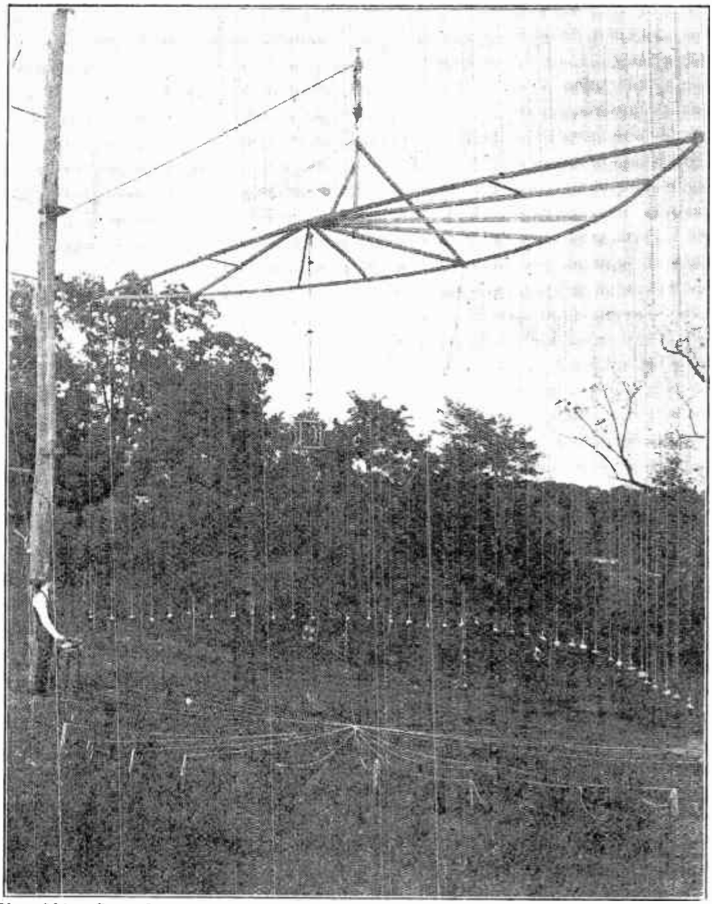


Fig. 391. Complete Installation of Generator, Antenna and Reflector, for 10-Meter Directive Transmitter.
(Bureau of Standards.)

(1 foot) apart. The frame was suspended from a rope and could be rotated. The wires were insulated from the frame and from each other. The focal distance was made one quarter of the wave length (8 feet 2.4 inches). It is important to have a frame of this shape in order to maintain proper phase relations and maximum reflection. The wave form of signals sent from this reflector is

similar to a parallel beam of light which has passed through a slit in an opaque screen. For receiving signals from this transmitter, at a distance greater than 150 feet, a receiver consisting of a detector and two stages of audio-frequency amplification was used, with an external heterodyne for detecting continuous-wave key transmission. The secondary consisted of a single loop of wire 12 inches in diameter, with a .00005-microfarad vernier condenser shunted across it. The rest of the receiver was of the usual type. The receiving antenna system consisted of a single wire, 14 feet 4 inches in length, including the single turn loop of a diameter of 1 foot, at the center. Antenna and loop were made of a single piece of number 12 B. & S. bare copper wire, and were suspended vertically from a pole, with a wooden support at the center for the loops. When receiving, the entire receiving set was suspended in the air at the center of this antenna.*

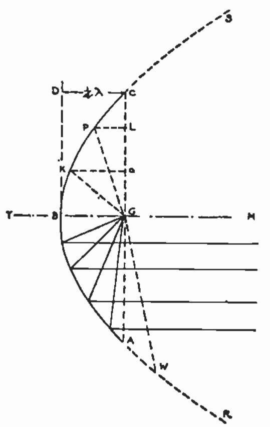


Fig. 392. Principle of Reflection of Waves from Parabolic Reflector. (Bureau of Standards.)

358. In a speech before the Institute of Radio Engineers, early in 1925, Dr. E. F. W. Alexanderson, of the General Electric Company, described a communication system employing extremely short waves, which are thrown high into the atmosphere, in a "curved radiation," the waves eventually returning to the earth, being only heard at the spot where they return. Dr. Alexanderson said, "So long as we are working with earth-bound waves we must use long waves for long distances because the earth absorption of the long waves is comparatively small. When, on the other hand, we use high-angle radiation with short waves we utilize a different form of wave propagation. These new tracks in the ether are being explored by systematic research work as well as by commercial communication. Thus a new phenomenon or law of nature has been established, though we are not able to give an adequate explanation. The curved space radiation with

*For further information, see *Scientific Paper of the Bureau of Standards No. 469, Directive Radio Transmission on a Wave Length of 10 Meters.*

short waves will undoubtedly open up new and open fields for radio."

Referring to the "scrambling and unscrambling" of communication, which was developed by John Hayes Hammond, Jr., Dr. Alxanderson said, "Signals from Europe are picked up in Belfast, Maine, scrambled together and sent into one wave band by a single transmitter to Riverhead, L. I. At Riverhead they are unscrambled into a dozen signals, which are fed into the long-wave receiving sets where they go through the usual process of detection and transmission to New York. The signals so reproduced are exact replicas of the original, and operators receiving them in New York are unable to distinguish whether they are the original signals or the scrambled and unscrambled signals. The fight against atmospheric disturbances and static has led us to build on long Island a central receiving station with two antennæ 10 miles long joined by a transmission line. This system eliminates practically all the static and intercepts on one antenna all the signals from stations in Europe. These signals are then automatically separated out in more than a dozen receiving sets and sent by wire to New York. There is only one kind of disturbance this system does not eliminate, a thunderstorm in the neighborhood of the station on the line from which the signals come."

The curved radiation and the scrambled waves are applicable to either telegraphy or telephony. It has been reported that in Italy the Hammond system has been applied to broadcast programs in such a manner that in order to hear anything intelligible the person listening must drop a coin into the receiving set, as is done in the land-line pay telephones. The radio receiving sets are leased to the people using them, and the money collected regularly by the lessors.

359. In operating a telephone broadcasting station it is not necessary to get the *brightest light* out of the vacuum tubes in order to have them operating most efficiently, the best adjustment being the lowest brilliancy which will permit efficient radiation. An easy method of checking the radiation and modulation of a telephone transmitter, where other means are not available, is to have someone listen with a receiving set. A short grunt has been found the best sound to use for this purpose, instead of singing or whistling. An approximate indication of the value of modulation obtained is the drop in current indicated by the antenna ammeter.

This should be deflected towards zero every time that a sound is made in the microphone. If the antenna ammeter is not deflected, the continuous waves are not being modulated. With a well designed transmitter, if the modulation is bad, it can usually be improved by adjusting the grid voltage, or the coupling. Too close coupling sometimes causes distortion. In some cases the modulator tube is affected by a reactive load due to too much inductance in the radio-frequency choke coil, or too large a capacity in by-pass condensers. If the choke coil is of too small a value, the modulator tube is likely to function imperfectly on account of power from the oscillator tube passing back into it. Also, this reduces the available operating power of the oscillator tube.

Transmitting tubes can carry a much heavier oscillating-current load than direct current. In operating, make sure that the tubes are oscillating. The simplest way of determining this is by observing the antenna ammeter reading. As direct current will not pass from one coil to another by induction, there will be no current in the antenna circuit unless oscillating current is being generated. If the plate becomes red hot, this indicates that the coupling between the grid and plate circuits is not correct, and the turns of inductance in the plate circuit should be varied until the plate resumes its normal appearance. If this is not successful, the grid capacity should be changed, or the antenna may be found to have an open circuit, or be shorted to the ground, or not in resonance. Iron or steel screws should not be used in the oscillating circuit, as they may become magnetic and cause trouble. The metal framework of the transmitter panel may also have a capacity effect which will cause losses, and all parts of the high-frequency circuit should be placed as far from the frame as possible.

When crystal control is used, too high a voltage must not be placed on the crystal, as this may break it. From 300 to 400 volts appears to be the limit that the crystal can stand. The crystals are a great help in keeping the oscillation frequency constant and, by eliminating waste due to wild oscilllations, the radiation is increased. However, the crystals are not imperishable. They need care, and have to be replaced occasionally.*

A milliammeter inserted in series with the primary of the

*See QST, May, 1926, for article on adjusting the crystal-controlled transmitter.

modulation transformer is a convenience in checking on the variation in current in the output of the modulator circuit. With a low-resistance microphone, the current indicated in this circuit may be about 30 milliammeters, with a modulation deflection of 1 to 2 milliammeters. Such a microphone is not practical for broadcasting, as it soon becomes overheated and inefficient from this cause. When a high-resistance microphone is used, the current in the circuit will be much less, and it is then necessary to use several stages of power amplification to obtain effective modulation in the main apparatus.

On account of the complicated overtone waves and "side waves" produced by applying sound waves to the radio-frequency oscillations used for transmitting, there may be some interference from a telephone station unless it is carefully controlled and equipped with appropriate filtering systems which assist in reducing interference. As the prominence of the side waves, of many different wave lengths, increases in proportion to an increase in the wave length used, radiotelephony on long waves, such as have been used extensively in high-powered radiotelegraphy, has not been satisfactory. Radiotelephone communication and broadcasting are generally conducted on comparatively short wave lengths, and commercial and amateur stations are allotted such frequencies for telephone use by the Department of Commerce. These wave length allocations are changed from time to time, and are sometimes "staggered" in an effort to secure a reduction of interference between the various stations. The antenna should be stretched taut to prevent swinging, and corresponding changes in wave length during transmission; and everything should be done to insure as good modulation as possible, as a distorted radiotelephone signal may cause more interference than a broad wave.*

While a broadcasting station is primarily a *radiotelephone* station, and not concerned with radiotelegraph communication, the law requires that a licensed radio operator capable of copying radiotelegraph signals be kept on watch at all times while the station is in operation in order to know whenever an SOS is sent. This is on account of the necessity of shutting down the broadcasting while the rescue work is going on. A spectacular instance experienced by broadcast

*See *Scientific Paper of the Bureau of Standards, No.* 423, *Operation of the Modulator Tube in Radio Telephone Sets,* by E. S. Purington.

listeners on the Atlantic coast was the SOS sent by the dirigible Shenandoah on the night when it broke loose from its moorings. At that time the broadcasting stations not only aided by ceasing regular transmission, but played an important part in the rescue work.

360. Radiotelephony has developed a new type of public speaker. The old style of arm-waving, ejaculating, emotional oratory has no place behind the microphone. If the speaker raises his voice above a dignified degree of volume, this will force the microphone diaphragm to rattle and produce a most unpleasant rasping noise in the receiving telephones of those who are listening. If he sways and jestures to emphasize certain points, this will cause his mouth to move to different distances from the microphone, and at different angles to it, and his voice will have a "coming and going" effect to those listening in. If, in what he may consider an effectively emotional appeal, he allows his idea to interfere with careful pronunciation of his consonants, his words will probably be totally lost in a meaningless jumble of sounds. The listeners will "tune him out" and bring in something pleasanter, which they *can understand.* If he talks too rapidly, also, the diaphragm may fail to give a faithful reproduction of what he is trying to say to his invisible audience. While it is far from necessary for prospective broadcasters to study radio, there is no doubt that some understanding of the construction and operation of the microphone in producing voice modulation will prove of help to them.

361. The same vacuum-tube oscillators, modulators and amplifiers that are employed in radiotelephony are applicable to the *transmission of photographs*, maps, printed and written pages, by radio. The additional equipment required is a light-sensitive device substituted for the microphone, and an apparatus for impressing upon this device the lines, or varying lights and shadows, making up the picture. Several devices have been invented for accomplishing this result. An apparatus invented by M. Edouard Belin, of France, is in use in Europe for the transmission, either by land line or radio, of facsimiles of money orders, etc. Halftones have been successfully transmitted by radio by C. Francis Jenkins, of Washington, D. C. The first demonstration of this was in 1922, although Mr. Jenkins had pub-

lished articles describing the contemplated process several years prior to this.

The Jenkins method of transmitting pictures is as follows: A ray of light is sent through prismatic discs of clear crystal glass, having a cam-like graduation of thickness giving a sharp edge where the thickest and thinnest portions meet. This graduated ring forming the outer part of the disc is the equivalent of a prism, which changes the angle of its faces as it rotates. The picture may be illuminated from behind, or *reflected* through the lens. As the light is passed

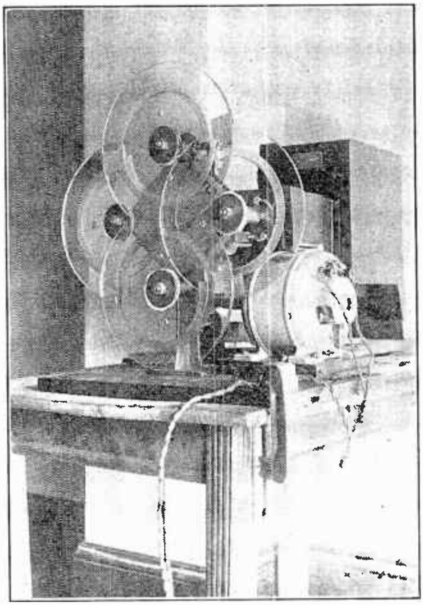


Fig. 393a. The Jenkins Prismatic-Disc Radio Picture-Projector.

through the picture in moving lines, the beam of light is directed into a small dark box having a small opening at one end. In this box is the equivalent of a microphone, in so far as its effect upon the electric current is concerned. It is a highly evacuated tube in which is placed an electrode consisting of a button of thallium sulphide, which has a resistance of about 50 ohms in the dark and 5 ohms in the light. There is no heated electrode in this tube. A "chopper" is placed in the path of the light beam, between the prismatic rings and the thallium sulphide "microphone," causing the direct current supplied to that tube to have about 500 fluctuations per second, as the variations in inten-

Fig. 393b. Photographic Reproduction of a Picture of President Harding, Transmitted and Rephotographed by the Jenkins Radio Picture Process in 1923.

sity of light and shade from the photograph are not sufficiently fluctuating by themselves to accomplish modulation.

At the receiving station, the modulated electric waves are run through a sensitive vacuum-tube receiving apparatus, with amplifiers, and in place of the receiving telephones there is another tube. Inside of the glass bulb are two conductors, one consisting of a large flat plate of nickel alloy, and another electrode consisting of a straight rod of the metal close to the plate but not touching it. To direct current this would offer an open circuit, but alternating current bridges the space between the two electrodes. The space in the bulb is filled with neon gas, which is extremely sensitive to light; and when current is conducted to this tube, the plate glows with a soft rose-colored light surrounded by a lavender brush. When this device is employed for making a *photographic record* at the receiving station, the ray of light from the neon lamp is directed into a camera, behind the lens of which is a duplicate of the prismatic arrangement used at the transmitting station. Then as the received waves vary in intensity according to the lights and shadows of the transmitted picture, the intensity of the light in the neon lamp reproduces these variations, and the spot of light, being made to *move across the photographic*

Fig. 398c. Jenkins Process Radio-Transmitted Photograph of Secretary Hoover, made in 1924, showing the improvement in blending of the lines.

plate by the rotating prismatic discs, traces, line by line, the shaded lines sent out from the original picture. All of the energy used to light the neon lamp is supplied from the receiving antenna, and if an opaque body stops the transmission of the light modulation at the transmitting station, the lamp at the receiving station will go out. The final picture obtained in this manner shows fine horizontal or vertical *lines* across it, according to the position in which it was mounted at the transmitting station.

This modulation can be *heard* on a crystal detector receiving set, and causes a peculiar sound easily recognized, by one familiar with it, as picture sending.*

In November, 1924, photographs were transmitted across the Atlantic Ocean, between the London station of the English Marconi Company and the Radio Corporation of America station at Marion, Mass. The system used was invented by Capt. R. H. Ranger, engineer of the Radio Corporation

*See the book *Radio Vision,* published in 1925 by C. Francis Jenkins. Also QST, December, 1925, for diagrams and instructions for amateur transmission of pictures.

Fig. 393d. Type of Weather Map Which is Sent Nightly to Ships at Sea by the Jenkins Method of Picture Transmission.

of America, and developed by that concern. *The following technical descripton of this process was supplied by the Radio Corporation of America:*

The Photoradiogram System of the Radio Corporation of America

For the actual operation of the transmitter, the picture, printed matter, or whatever is to be sent, is first photographed on an ordinary camera film. This is developed and then placed on a *glass cylinder,* being held firmly in place by metal clips. The picture is now ready to be transmitted. Inside this glass cylinder is an incandescent lamp, the light from which is focused in a minute beam onto the film as the cylinder is set in motion. As the light and dark portions of the picture are traversed by the light beam, the intensity of the ray is changed. This ever changing beam, after having passed through the film, is again focused through another lens outside the cylinder onto the sensitive element of a *photo-electric cell,* a recent development of the General Electric Company, which transforms the light waves into electrical impulses or waves, which can be transmitted by radio much the same as a regular dash and dot message.

This is commonly spoken of in the laboratory as the "eye" of the transmitter. The electrical resistance of this cell changes in accordance with the amount of light which falls upon it, and in this way takes care of the shading of the picture in transmission. It is a pear-shaped bulb about 2½ inches in diameter. The positive electrode enters through the neck and makes no contact with the walls. The negative electrode enters through the wall and makes contact with the metal-coated inner surface of the bulb, with the exception of the small clear space 1½ inches in diameter

Fig. 394a. The First Photograph Flashed Across the Ocean.

about opposite the negative lead, which space serves as a window for light admission. The whole of the inner surface of the globular part of the bulb is metal coated, and, therefore, opaque to the light. The bulb is coated on the inside with a highly reflecting thin film of metal, which prevents light from entering except through the window, and which also serves to insure good conductivity of the electricity. On the metalized surface of the bulb there is a deposit of *potassium* compound. *This surface produces a current which depends on the amount of light it receives.*

Thus when brightly illuminated through the window it gives much more current than when darkened. The current enters the photo-electric cell through the cathode, which is on the side of the bulb. *The light-sensitive bulb coating gives off electrons, the number depending upon the amount*

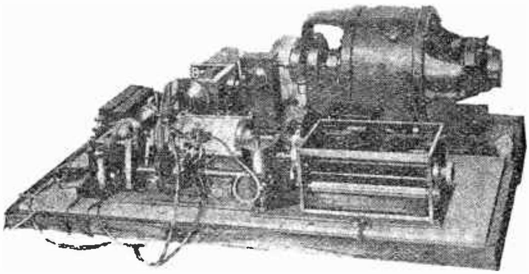


Fig. 394b. The Recording Part of the Radio Corporation of America Photoradiogram Apparatus.

of light received. These electrons pass through the space to the anode, or positive electrode, and complete the circuit. The amount of current depends on the number of electrons given off, dependent in turn on the amount of light. The instant the slightest change in the amount of light reaches

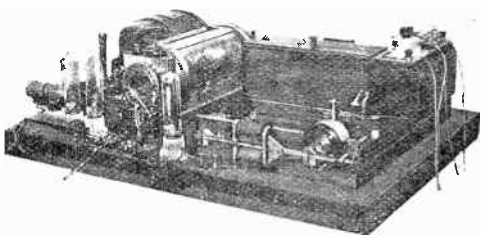


Fig. 394c. Radio Corporation Picture Transmitter.

the cell, a corresponding change in the output current of the cell takes place. In this way the "eye" of the transmitter is able to "see" even the tiniest light variations; in fact, the "eye" sees and records electrically millions of different current impulses as the film sweeps by the light beam from inside the cylinder.

From Light to Electric Current

The photo-electric cell is, therefore, responsible for reproducing an infinite number of different electric current values which correspond with the light or dark areas of the picture being transmitted. In order to cover all of the original film, the glass cylinder is rotated *back and forth* and in this way the entire surface is eventually exposed to the piercing light beam. The film rotates through an angle equal to the width of the picture and the electric camera itself advances down the length of the picture one notch at a time. Thus, line upon line, the whole picture is covered.

From Electric Waves to Radio Waves

(Note: This refers to the geographical locations of the first tests.)

After the signal impulses or electric waves from the photo-electric cell pass through a series of vacuum-tube amplifiers, they are fed into a *modulating* device ready for transmission. The *electrical interpretation of the picture* is then transmitted over land wires from the London laboratory to the Carnavon, Wales, high-power transmitting station of the Marconi Wireless Telegraph Company, Ltd. *Here the electric impulses on the land wire operate small relays which turn on and off the high-value currents flowing from the 200-kilowatt generator to the antenna system.* This high-power electrical energy leaving the antenna in *interrupted* impulses, similar to dots and dashes of the telegraph code, creates the ether waves which carry the photograph through space 3,000 miles to the receiving station on this side of the Atlantic, located at Riverhead, Long Island. The new device does not require the preparation of any special radio circuits for efficient operation.

The Receiving Station

At Riverhead, Long Island, in the Radio Corporation's central receiving station, the operator tunes in to the Carnavon station. He *receives the picture just the same as he would a radiogram*, but *instead of dots and dashes which he can read he receives an undecipherable series of impulses.* These pass through a bank of vacuum-tube amplifiers and are then sent by wire to the laboratory of the Radio Corporation located in the building in Broad street.

Here this unintelligible code, carrying the photograph, is translated back into black and white, recording the original picture much in the style of a stippled engraving.

The Unscrambler

This device in the RCA Laboratory (the final operation involved between transmitter and receiver) *decodes* or *unscrambles* the complex photo message, giving each individual electrical pulse of energy a definite task to perform in reassembling the picture. The picture is reproduced in duplicate at the receiver, both on a paper record and on a photographic film. The paper upon which the record is made is wrapped about a rotating cylinder, which, in size and appearance, much resembles the early type wax phonograph record. A specially constructed *fountain pen* bears against this just as the needle of the phonograph does on a record. The pen is attached to an electrically controlled lever in such a way that every pulse of electrical current which passes through the magnet coils of the relay lever draws the pen to the surface of the paper, making a fine ink mark. A changing current fed through the magnet coils causes the pen to wiggle in step with the current impulses, thus giving the artistic *stippling* effect in the reproduced picture. (Note: The accompanying photograph of President Coolidge is made up of *dots.*)

Absolute Synchronism Necessary

One of the outstanding requirements in sending pictures by radio or wire is absolute synchronism of the sending apparatus with the receiving device, otherwise distortion will occur. If the receiving apparatus should lag the slightest particle of time behind the transmitting set, the received picture would be blurred and unrecognizable. This necessary synchronism is maintained by the use of special driving motors, one geared to the transmitting cylinder and the other geared to the receiving cylinder. These motors, although separated by 3,000 miles, maintain the same speed. To check against any change which might occur, special controlling mechanism is attached to the receiver, based upon the constant pitch of the tuning fork.

Photographic Record

The making of the ink record is visible in all its operations. The wiggling of the fountain pen can be watched as the cylinder rotates back and forth, gradually building up the picture. The photographic record is made on an ordinary camera film inside a specially constructed camera, a beam of light playing upon the film in place of the pen upon the paper. This is developed as any film, and as many prints can be made from it as desired.

CHAPTER 36

Modern Vacuum-Tube Receivers and Amplifiers

Honey-comb-Coil Regenerative Receiver—Reinartz Circuit—President Harding's Set—Power Tube for Amplifier—Audio-Frequency Transformer Shielded—Mutual Conductance and Amplification of Hard Tube—Miles of Amplification Table of Audibility Ratios — Separate Audio Amplifier — Jacks and Plugs — Loud Speakers — Phonograph Loud-Speaker Attachment—Radio-Frequency Amplification and Transformers—Table of Radio-Frequency for Transformers—Standard Five-Tube Radio and Audio-Frequency Receiver—Stabilizers—Resistance Coupling—Choke-Coil Coupling Tuned Radio Frequency—British Receiving Circuits—Armstrong Super-Regenerative Circuit — Neutrodyne — Bremer-Tully Receiver — Browning-Drake Receiver—Reflex — Fada Reflexed Neutrodyne — Superheterodynes, Various Types — Transformers and Coupler for Superheterodyne — King George's Set—Second-Harmonic Radiola—Ultradyne—Push-Pull Amplifiers —Roberts' Set—Zenith Super X—Atwater Kent Receiver—Crosley Receiver —Marconi Four-Element Tube Receiver — 40-Meter Receiver — Receivers Operated from A. C. Power Line—Wired-Wireless Receiver—Alternating-Current Power-Line Receiving Tube—Operating 1,800 Head Phones from One Neutrodyne—Loop Antenna Arrangements—Table of Inductance of Coil Antennæ—Trouble Shooting in Receivers — Transposed Antenna — Taylor Multiple Reception for Apartment Houses—Wave Traps for Selective Tuning—McCaa Static Eliminator.

362. While much can be accomplished in the way of receiving with one tube and a regenerative feed-back, it is usually desirable to add one or more stages of amplification to the vacuum-tube detector circuit. Regenerative ampli-

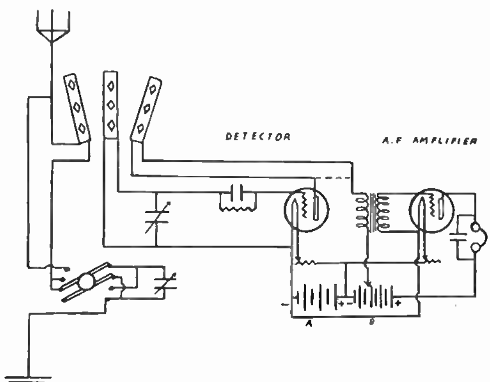


Fig. 395. Honey-comb-Coil Regenerative Receiver with One-Stage Audio-Frequency Amplifier.

fication was explained in chapter 33. In the circuit shown in figure 395, the tickler coil may be cut out, when desired, as indicated by the dotted line. The honey-comb coils are a fixed inductance, hence all the tuning is done with the condensers. The audio-frequency transformers, which respond to the audio-frequency output of the vacuum-tube grid-condenser and gridleak detector circuit, as explained in paragraph 303, have a laminated iron core. The ratio may be from 3 to 1 up to about 7 to 1, according to requirements. Too high a ratio of transformation will produce distortion of the sound waves and interfere with faithful reproduction of the signals. Also, while the signals are magnified, all other noises and static are magnified at the same rate, so there is a limit to the ratio which may be practical. The secondary of the audio transformer, under the influence of the magnified pulsations in the primary, produces a magnified fluctuation in the voltage of the grid of the second tube, which produces a corresponding fluctuation in the plate current of that tube, and a louder signal is heard in the receiving telephones than would be the case if they were placed in the detector circuit. A higher plate voltage is used for the second tube, which still further increases the volume of the signals. The total effect is the same thing in

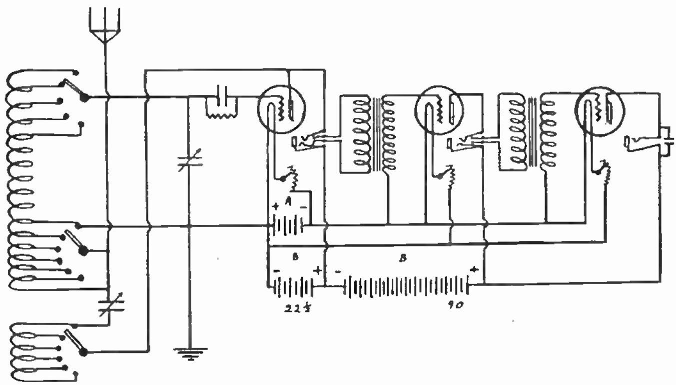


Fig. 396. Reinartz Receiver with Two-Stage Audio-Frequency Amplifier.

a receiving system that the amplifier circuit of a master-oscillator transmitting system accomplishes. Two stages of audio-frequency amplification are so generally used now, that this may be considered an established custom. More than this has not proved successful under ordinary conditions, although a power tube, as in figure 397, is often used to operate a loud speaker. The same amount of power would make the diaphragms of head phones rattle most unpleasantly.

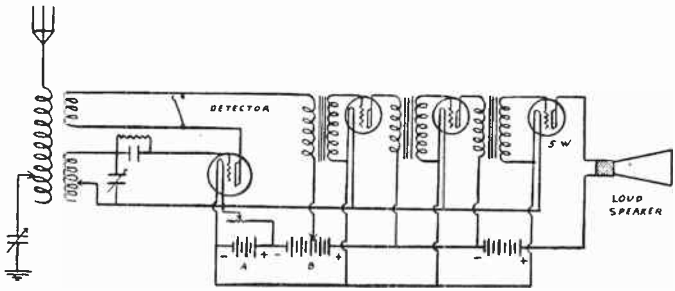


Fig. 397. Circuit Diagram of Receiving Set which was Installed in the White House by U. S. Navy Experts for the late President Harding.

Audio-frequency transformers of recent date are generally somewhat heavier and made of coarser wire than were the earlier types. It has been found that there is less danger of burning them out, when the larger wire is used, and it is also possible to obtain more plate current by this reduction of resistance. The design of the transformer is important, and has much to do with the results obtained. In most cases the coils are covered with a metal shield to counteract induced oscillations from the tubes or other parts of the circuit. In case there is a "howling" in the telephones, when placed in the last stage of an audio-frequency amplifier, this may usually be overcome by connecting a wire from the shield of the transformer to the ground wire of the set. The transformer primary and secondary windings are generally wound over a laminated iron core, of the shell type, and mounted with the edge of the laminated shell magnetic path exposed, as shown in figure 398.

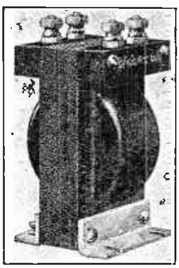


Fig. 398. Shielded Audio-Frequency Transformer.

363. The highly evacuated tubes, frequently referred to as "hard" tubes, are invariably employed in amplifying circuits. And while in some cases they may be operated on separate batteries, it is an established custom to use the same filament and plate power for all of the tubes in the receiving set, connecting the tubes in parallel. By referring to the characteristic curves on pages 324-325, the amplification factor of the vacuum tube will be recalled, and it can be

seen how tubes having certain characteristics may be most suitable for use as detectors and others as amplifiers. The suitable tubes, together with appropriate transformers and connecting devices are generally referred to as a unit, known as an amplifier. Referring to this, E. T. Cunningham says, in his booklet, *Radio Tube Data:* "An amplifier is most readily understood if looked at as a telephone repeater; that is, a device capable of receiving telephone currents and giving out other telephone currents of the same wave form but of a greater magnitude. The increased energy in the output circuit is supplied by the plate or 'B' battery. Electric currents at both voice frequency and radio frequency are often amplified as many as ten or twelve times between the microfone in the studio and the sound reproducing device of the receiving set. The amplification constant of a tube is a factor that expresses the maximum voltage amplification it is possible to obtain with that tube. If a tube such as the C-301-A has an amplification constant of 8, it is possible to obtain a maximum voltage amplification from that tube of 8 times. The mutual conductance of a vacuum tube gives a measure for the controlling effect of the grid potential on the plate current. Since all vacuum-tube circuits involve the use of grid potentials to control plate current this is a very important unit and expresses very accurately the degree of merit of the tube when used as amplifier, detector or oscillator. It is always desirable to have the mutual conductance as high as possible. A high mutual conductance means that small variations in grid potential will cause relatively large variations in plate current. The mutual conductance of any tube can be computed directly from the plate impedence and the amplification constant.

Where Gm = mutual conductance in micromhos,
μ = amplification constant
Z = impedence

$$Gm = \frac{\mu \times 1{,}000{,}000}{Z}$$

Since amplification plays such an important part in both radio transmission and reception it is obviously necessary that there be some convenient unit for measuring the amount of amplification between the input and output of an amplifier. For many years prior to the advent of the vacuum tube, transmission losses in telephone lines were measured in terms of the *mile* of standard No. 19 gauge cable at a frequency of 796 cycles. When the vacuum tube came into use as a telephone repeater this same unit was adopted as the standard for measuring repeater or amplifier gains. If a circuit is said to have an amplification of 25 miles, it means that it would take 25 miles of standard No. 19 gauge telephone cable to reduce the signal to its original value. The gain in miles always depends directly on the power amplification, a given ratio between input power to the amplifier and output power from the amplifier always corresponding to the same number of 'miles gain.' In a well designed amplifier circuit both the current and the voltage amplification ratio will be equal to the square root of the power amplification ratio. Under these conditions it is most convenient to think of the gain in miles as depending on the current ratio. This makes it possible to get a fairly accurate comparison between gain in miles and the increase in audibility or sound intensity, since within certain limits, depending on the mechanical construction of the sound reproducing device, sound intensity is directly proportional to current."

TABLE SHOWING CURRENT OR AUDIBILITY RATIOS AND POWER RATIOS FOR GAINS BETWEEN 1 AND 30 MILES OF STANDARD NO. 19 CABLE.
(Cunningham)

Miles of Standard Cable	Current Ratio or Audibility	Power Ratio	Miles of Standard Cable	Current Ratio or Audibility	Power Ratio
1	1.11	1.24	16	5.71	32.7
2	1.24	1.54	17	6.94	40.7
3	1.38	1.92	18	7.11	50.6
4	1.54	2.39	19	7.92	62.8
5	1.72	2.97	20	8.83	78.3
6	1.92	3.70	21	9.84	97.4
7	2.14	4.60	22	11.0	121.1
8	2.39	5.72	23	12.25	150.7
9	2.66	7.12	24	13.65	187.1
10	2.97	8.85	25	15.2	233.4
11	3.31	11.02	26	17.0	289.8
12	3.70	13.7	27	18.9	359.8
13	4.12	17.0	28	21.1	447.8
14	4.49	21.1	29	23.5	559.2
15	5.12	26.37	30	26.3	693.5

364. It is often convenient to have an audio-frequency amplifier arranged as a separate unit, so that it can be attached to the output of different detector circuits, either vacuum tube or crystal. *Jacks* connected in the various circuits make it possible to get different degrees of amplification as desired. Jacks have been in use from the early days of telegraphy and telephony, from which arts they have been adapted to radio apparatus. At first, the use of plugs in radio apparatus was confined to the contacts for the head telephones, but they were later found useful in several other places. Telephone jacks, which simply connect the telephones to the circuit, or leave the circuit open when the plug

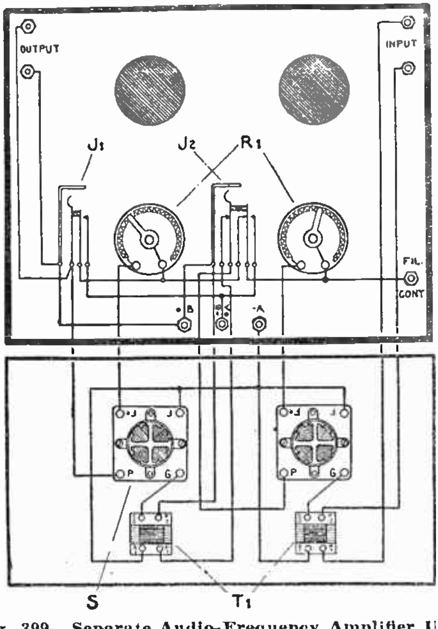


Fig. 399. Separate Audio-Frequency Amplifier Unit.
(Federal Telephone & Telegraph Co.)

is withdrawn are known as "open-circuit jacks." Other jacks are made for inserting the telephone plug into the first stage of a two-stage amplifier, or into the detector circuit, and automatically cutting out the transformer, as shown in figure 402. This type of jack closes the circuit to the primary of the transformer, when the plug is withdrawn.

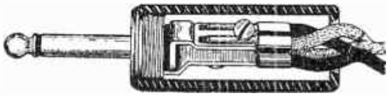


Fig. 400. Cross-Sectional View of Plug for Holding Two Head Telephones. (Carter.)

Still others are known as filament-lighting jacks. These perform all three functions. For instance, in figure 404, if the telephone plug is inserted in jack No. 1, only the de-

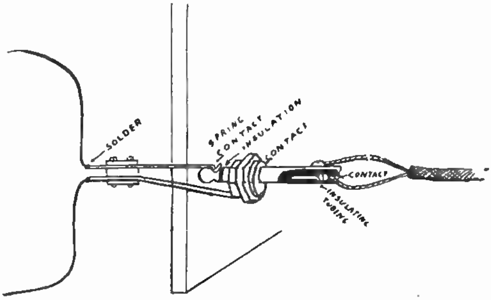


Fig. 401. Simple Open-Circuit Jack with Plug Inserted.

tector output passes through the receiving telephones, and the filament circuit to tubes A-1 and A-2 is opened. The transformers of the amplifier are also disconnected. If the

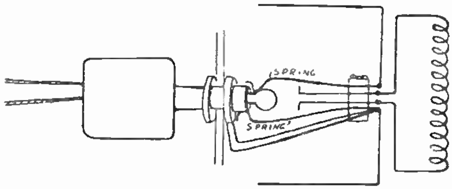


Fig. 402. Simple Closed-Circuit Jack.

plug is inserted in jack 2, the detector tube and tube A-1 are lighted, and the first transformer is in use, and the output of the first stage of the audio-frequency amplifier passes

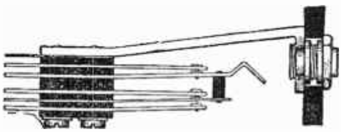


Fig. 403. Filament-Lighting Jack.

through the telephones. The filament and transformer of the second stage are disconnected. By inserting the plug into jack 3, all three tubes are lighted, and the output of the second stage of amplification passes through the phones, giving much louder signals than when the plug was in jack 1, and somewhat louder than when in jack 2. The jacks in figure 399 are automatic filament-lighting also. Disconnecting the filaments when the tubes are not in use, increases the

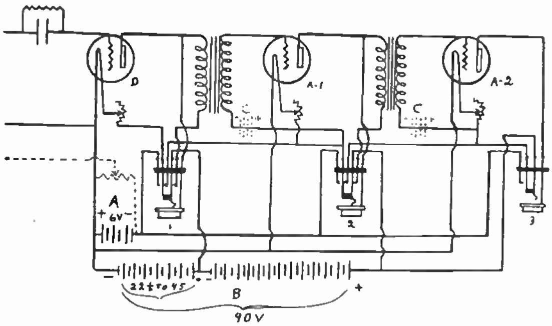


Fig. 404. Connections for Filament-Lighting Jacks in Two-Stage Amplifier.

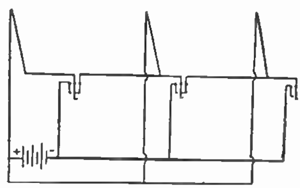


Figure 405. Filament Circuit of Fig. 404.

life of the tubes. The different springs in the jack should always be tight and make good contact, and the plug must reach the right position to make contact between each side of the telephone cord and each side of the circuit to which the telephone is to be connected. As diagrams showing filament control and transformer-connecting jacks are somewhat complicated to draw and to trace hastily, jacks are not always included in receiver diagrams, but may be added to any receiving circuit if desired. Filament-lighting jacks are not employed as much as formerly, on account of their being a constant source of trouble in receiving sets, especially after used for some time.

In some cases it is found an advantage to use a negative grid bias on tubes in an audio-frequency amplifier. This reduces distortion of the sounds heard in the receiving telephones by making the tube work on the most desirable point of its characteristic curve. This bias may be obtained by adding two or three small flash-light dry cells as indicated by the dotted lines in the grids of the amplifier tubes in figure 404, or one battery may be used for both tubes, by connecting the grid of tube A-2 to the negative terminal of the C battery in the grid of tube A-1. By arranging the battery in series with the grid of an amplifier tube so that the potential of the grid is negative, we prevent the grid from absorbing any of the electron flow within the tube, the grid not being allowed to become positive with respect to the filament, and this usually improves the operation of the amplifier. Incidentally, the same or greater volume will be obtained, with minimum distortion, and a conserving of the "B" battery. It is not the total quantity of current passing from filament to plate that causes the loudest signals in the telephones, but the greatest *variation* in the plate current. Hence, the same, or increased variation, with the total quantity of current reduced, does not decrease the volume of the signals, but does save plate current.

365. With two or three stages of audio-frequency amplification it is possible to use a "loud speaker," so that a whole room full of people may hear the signals without being obliged to wear individual sets of head telephones. This is

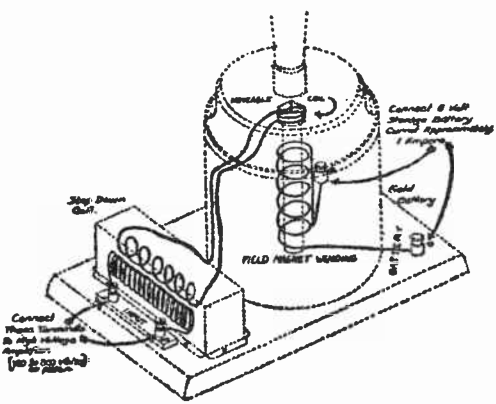


Fig. 406. Phantom View of Magnavox.

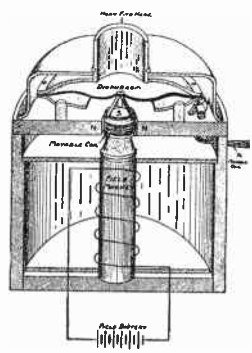


Fig. 407. Cross-Sectional View of Arrangement of Working Parts of Magnavox.

not only useful for home receiving apparatus, but in the professional ranks it has a wide application. In many of the large stations operated by the government, some form of sound-magnifying device is installed and, while on duty, it is not necessary for the operator to listen with the head telephones continually. When code signals are heard in the horn, he can place the head telephones over his ears, if he finds it easier to copy that way. There are several makes of loud speakers, equipped with various types of horns or sound chambers. The reverberations caused by the metal horns have been overcome by the use of gutta-percha, paper fiber, knit goods, and the like. One make employing a large conch shell for a horn gives an exceptionally clear tone. One of the first loud speakers was named the telemegafone, and later the magnavox. The magnavox is an electrodynamic device operating on a principle quite similar to that of a motor, except that the movable part travels in a vertical direction instead of rotating, as in a motor. A small coil is attached to the center of a large diaphragm by a small pin, and this coil is placed in a strong magnetic field. The magnetic field to which the coil is subjected is steady. Then as the magnetism of the small coil attached to the diaphragm is varied in accordance with the current delivered to it from the audio-frequency amplifying circuits of a receiving apparatus, it is drawn into or repelled away from the steady magnetic field, and the diaphragm is caused to move a considerable distance, and to vibrate in such a way as to *greatly magnify the intensity of the sound waves.* A *step-down* transformer is connected as shown in figure 406. This is used because the movable coil is surrounded by an iron field which has the effect of a closed secondary and which has a low impedence. The early type of magnavox is a *current* operated device, and the more current there is passed through the small movable coil,

Fig. 408a. Late Type Magnavox Cone Loud Speaker Requiring no Battery. (Cornell Model.)

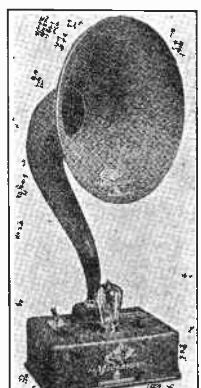


Fig. 408b. Magnavox One-Stage Power Amplifier and Loud Speaker Combined.

the louder will be the signals. As it requires considerable power for the most successful operation, the manufacturers construct a power amplifier to be used with it. This is designed for power tubes, such as used in transmitting apparatus, and may be operated with from 100 to 500 volts on the plates, from banks of "B" batteries, or other

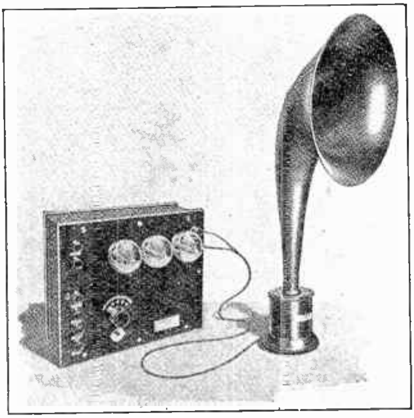


Fig. 409. Western Electric Loud Speaker and Power Amplifier.

source of high voltage and small current. Some models combine the loud speaker and amplifier in one piece of apparatus. Among other well-known makes of loud speakers, is that of the Western Electric Company, who also manufacture a power amplifier to be used in connection with their loud speaker. In figure 410, it will be seen that the working principle of this apparatus is somewhat similar to that of the Baldwin telephone. The current of amplified value is passed from the audio-frequency vacuum-tube circuit through the leads marked L, to the armature coil, which in this case is stationary. The varying magnetism set up in this stationary

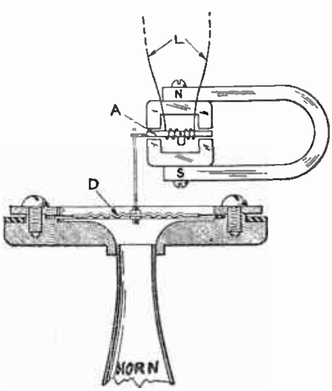


Fig. 410. Working Principle of the Western Electric Loud Speaker.

coil by the audio-frequency currents passing through it causes the movable iron-core armature, A, to vibrate about its pivot, and this vibration is conveyed to the armature by the pin connected between the two. The power amplifier made to be used with this usually employs three Western Electric 5-watt power tubes. These tubes are operated with a filament voltage of 6 volts. About 9 milliamperes of current is used on the plates, at from 100 to 130 volts.

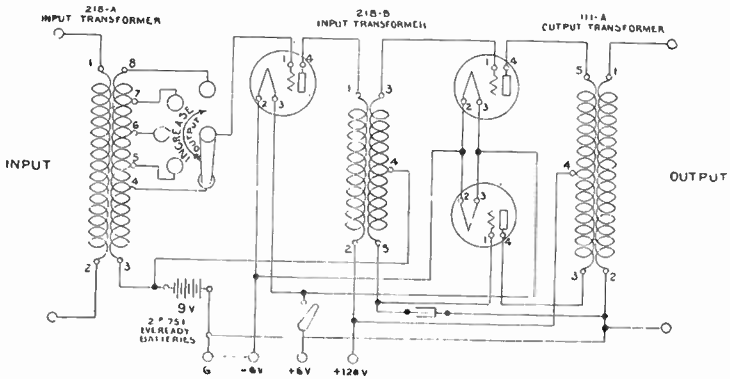


Fig. 411. Wiring Diagram of Western Electric Power Amplifier.

Some makes of loud speakers are equipped with cone-shaped sound reflectors, and these in some cases give more pleasing tonal quality than the horns. However, many of the unpleasant reverberations heard from horns are caused by improper tuning of the receivers.

A small electrodynamic device, serving as an attachment for using the sound chamber of a phonograph for reproducing the signals, has proved very satisfactory. The phonograph sound chamber generally gives a pleasanter tone than a horn.

Several loud speakers, not requiring battery current for operation, consist of a good telephone receiver with a horn attached. Naturally they do not give as much volume as the others.

366. Many distant signals may be intercepted by a receiving antenna, but not heard in the telephones, no matter how many stages of audio-frequency amplification are used, because they are too weak to cause grid voltage variations of

sufficient rise and fall to operate the detector circuit. *There is no advantage in the use of radio-frequency amplification for nearby signals,* but by their use the *distance* range of a receiving set may be increased many times. This consists simply of arranging one or more stages of amplification between the detector and the antenna in such a manner that the energy of the weak signals is gradually built up before being passed through the detector circuit. This may be considered nearly as important a discovery as the principle of regeneration, and it has opened up a wide field of usefulness for vacuum-tube receivers, which hitherto was closed. Also it has made possible the practical use of the loop an-

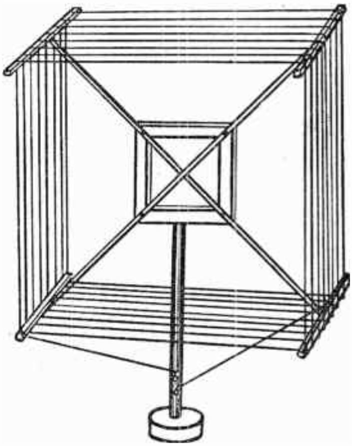


Fig. 412. Loop Antenna.

tenna, which picks up so little energy that it can not be employed to feed the signals directly into the detector circuit. *In each radio-frequency circuit the signals are rectified, but not reduced to audio frequency, and the radio-frequency pulsations in the primary of each transformer set up an undulating current in the secondary, which is rectified again.* The "B" battery energy is added to the signal strength in each stage of amplification by the action of the tube. Amplification in cascade circuits is accomplished through the *dynamic characteristic* of the tubes, which depends upon the construction and constants of the tubes used, and also upon the resistance and impedence in the plate circuit. Variations in grid voltage produce corresponding variations in the plate potential. This is because the plate potential varies inversely with the plate current. When the plate current is large, the plate voltage drops, and when the plate current is reduced by the action of the grid, the plate potential rises.

367. The transformers used in radio amplifiers may be air cored, or they may have cores of fine steel laminations. Some of them are wound over a sealed tube containing steel filings. Air-core transformers give better amplification at radio fre-

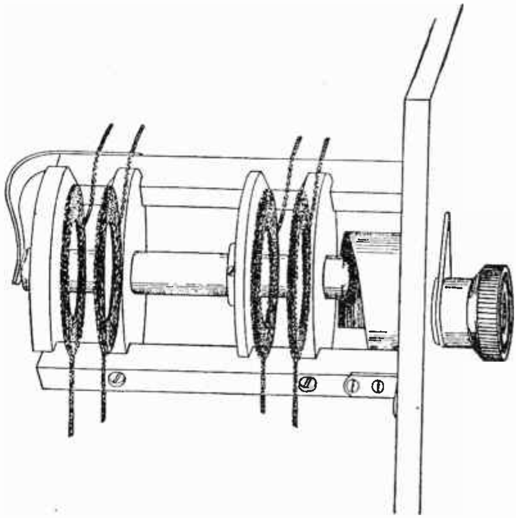


Fig. 413. Two Flat Air-Core Radio-Frequency Transformers Mounted on a Rotating Shaft by Means of Which the Coupling Between Them May be Varied.

(Bureau of Standards.)

quency under certain conditions, but have a narrow tuning range, so that it is necessary to employ different sets of transformers for different frequencies. In some cases two bands are provided for by taking off taps from the primary and secondary windings. The air-core transformers must be carefully matched, whereas this is not necessary with the iron-core type. The radio-frequency transformer having a steel core can be used for a wider range of wave lengths. In some cases the primary and secondary of the radio-frequency transformer may be made movable, and it is found that by varying the coupling between them, it is possible to

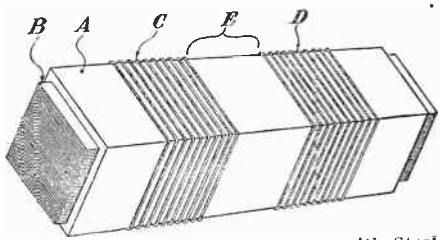


Fig. 414. Radio-Frequency Transformer with Steel Core. (Bureau of Standards.)

obtain, within limitations, a wider band of wave lengths. The coils shown in figure 413 are wound with No. 38 B & S single-covered copper wire, in the basket or honey-comb style of winding, and have an inside diameter of 1¼ inch and an outside diameter of 1¾ inch. There are 350 turns of wire on each coil, making them 3/32 of an inch thick. The ratio of transformation is 1 to 1. When the coils are about one-half an inch apart, they will operate on 600 meters, and the wave length increases as they are moved closer together, up to about 1000 meters. The increase in wave length, caused by moving them towards each other, is due to an increase in capacity. Mr. P. D. Powell, in *Scientific Paper of the Bureau of Standards, No. 449,* gives a description of a steel-core radio-frequency transformer, which has been the basis of some commercial types. A drawing of this is shown in figure 414. A is a tube of bakelite, or other insulating material, having an inside measurement of ½ an inch, and about one-sixteenth of an inch thick and four inches long. The core is indicated at B. This consists of silicon steel laminations not more than .001 of an inch thick which has small losses from eddy current. The primary and secondary are shown at C and D, the space marked E representing a distance of one-fourth of an inch left between the two windings on the tube. The windings in the transformer described were made of No. 44 enameled copper. The number of turns are determined by the frequency of the currents to be used, and the coils always consist of a single layer. After being wound the coil is varnished. The following table gives the number of turns of wire used for different frequencies.

The outside ends of the coils, when constructed as in figure 414, should be connected to the grids and plates of the tubes,

TABLE FOR STEEL-CORE RADIO-FREQUENCY TRANSFORMERS

(*Bureau of Standards*)

Frequency in Kilocycles Per Seconds.	Number of Turns On Each Coil.
1500 to 750	175
750 to 375	300
375 to 187	500
187 to 94	800

and the inside ends to the battery circuits. This reduces capacity effects. All wiring used in the construction of radio-frequency amplifiers should be as short as possible for connecting the various parts of the apparatus, which should be placed a good distance apart to cut down "howling" due to stray oscillations caused by uncontrolled capacities. It is better to have no sharp corners in the wires, as there is always some loss in such a turn. Wires should be bent in a gradual curve. The radio-frequency transformers are often placed in diagonal relation to each other, and as far apart as consistent with the plan of the set, so as to prevent any inductive feed-back between them.

In figure 415 is shown the standard diagram for a five-tube receiving set employing radio and audio-frequency amplifying circuits. This is the most common number of tubes for this type of apparatus. The set may be used with a loop antenna, or elevated antenna and receiving transformer. The resistance shunted across the filament battery is called a *stabilizer*, and is the same thing as the voltage divider referred to in paragraph 264. The condenser

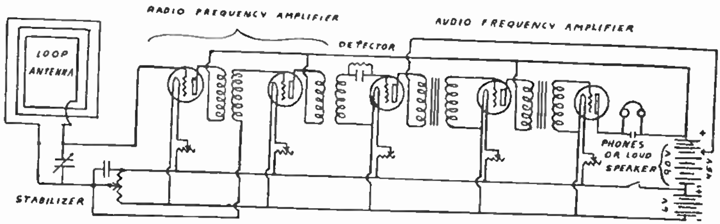


Fig. 415. Standard Diagram of a Five-Tube Receiving Apparatus Consisting of One Detector Unit, Two Stages of Radio-Frequency Amplification and Two Stages of Audio-Frequency Amplification.

around the stabilizer is sometimes omitted, but it keeps the stabilizer resistance from causing excessive damping in the high-frequency circuits. *Variable contact to this resistance gives a control of the grid voltage of the high-frequency tubes, which assists materially in reducing undesirable oscillations,* which cause unpleasant "squeals" in the telephone. The resistance usually takes the form of a "potentiometer" of about 300 ohms. Three tubes is about the limit that can successfully be operated in a radio-frequency amplifying circuit, with one stabilizer, but four or six may be employed if additional stabilizing arrangements are made, by adding a resistance and a condenser midway between the battery and the stabilizer which is attached in the first circuit.

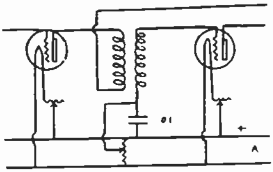


Fig. 416. Method of Adding Extra Stabilizers.

368. It is possible to couple the amplifying circuits by other means than the two-coil transformer. They may be coupled by a resistance, a choke coil with an iron core, a tapped choke coil without a core and shunted by a variable condenser, or by a variometer. In Europe the resistance coupling is employed extensively. The transformer is most used in this country for all-around work. A resistance-coupled radio-frequency amplifier is illustrated in figure 444 as a part of a superheterodyne receiver. In this the audio-frequency variations of the grid potential of the first amplifier tube cause a corresponding variation of the plate output of that tube. This in turn causes a duplicate and amplified variation in the grid potential of the second tube, through the coupling condenser, by causing a variation in the potential across the coupling resistance, and so on, throughout the cascade circuits, gradually building up the energy of the signals. On account of the condensers being placed between the grids and plates of the tubes, the grid leaks must be connected as shown, so as to provide a leakage path from grid to filament for each tube. The amplification obtained is confined solely to the amplification characteristics of the tubes in the circuit, as the resistance is non-inductive; and three tubes are required to obtain the volume gained from two when transformer coupled. Exceedingly

high plate voltages are required for successful operation of this type of amplifier—much higher than for other types of coupling. The coupling condenser may have a capacity of from .1 to 1 mfd. If too small the signals are likely to be weak, and if too large the quality of the signals may be poor. The resistance of the coupling units is generally from 50,000 to 100,000 ohms, and should be about the same as the internal resistance of the tubes with which they are used to give the best results. One type of resistance sold for this purpose is composed of lavite. Sometimes they are made by coating a piece of bristol board 2 inches long and 1½ inches wide with a mixture of Higgins' American india ink and powdered graphite, 6 parts ink to 1 of graphite. After this has been dried it is wrapped around an insulating tube 2 inches long and ½ inch in diameter and clamped into place with two narrow strips of brass which serve as contacts to which to fasten the connecting wires. The treated bristol board is covered with string wound evenly over the entire length of it to protect the resistance material, and then varnished. One advantage of this type of amplifier is that, having a coupling without inductance, its operation is not confined to any particular band of frequencies, as with the inductive couplings.

There is no particular object in employing resistance coupling for radiotelegraphy, but for broadcast reception it is well worth while. Voice and music are reproduced clearly, with distortion reduced to a minimum.

369. Exactly the same circuit as that employing the resistance coupling may be used with choke coils substituted for the resistances. This has the advantage of not requiring such high plate voltage for the amplifying tubes. The dynamic characteristic of the tube is such that when a choke coil of high impedence is placed in series with the plate, the voltage in the coil becomes a magnified reproduction of

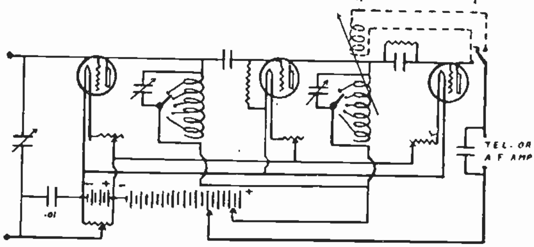


Fig. 417. Tuned-Choke-Coil Amplifier.

the grid voltage of the same tube. The alternating current passing through the coil sets up a counter emf. which has a tendency to oppose any change in the direction of the current, so that the *current* which eventually passes through it has little variation in it, but the variation in *pressure* in the choke coil continues to exist. When choke coils are used for coupling various stages of radio-frequency amplification this variation in pressure in the coil is impressed upon the grid of the next tube, and the amplification depends upon the characteristics of the tube. Another advantage of the choke coil is that by shunting it with a variable condenser, it is possible to obtain a tuning for various wave lengths. Sometimes in addition, the coils are made with taps and a varia-

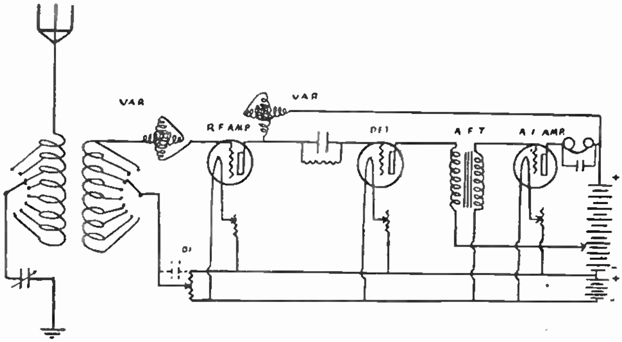


Fig. 418. A Tuned Radio-Frequency Amplifier Receiving Set.

ble contact. Where such a switching device is used, it has been found convenient to arrange all of the movable switch arms on one shaft so that they are rotated simultaneously. The choke coil and condenser in this kind of apparatus may be replaced by a variometer. In figure 418 a circuit is shown in which a radio-frequency amplifier is inductance coupled to the detector through a variometer. A variometer is also used in series with the grid of the first amplifying tube for additional wave length tuning. This is optional and would not be used if a condenser were shunted across the secondary of the antenna transformer. The variometer-coupled receiver is not practical with more than one stage of amplification, as tuning becomes too difficult.

370. Many difficulties have been encountered in the development of an efficient radio-frequency amplifier. The first one was the fact that a "straight radio-frequency" system, such as indicated in figure 415, will respond to only

a narrow band of frequencies. Arrangements have actually been made for plugging radio-frequency transformers of different wave length into clips, as fuses are plugged in. When a *tuned* radio-frequency amplifier is constructed, unless everything is unusually well balanced, annoying squeals and whistles will be heard in the receiving telephones. These are caused by interaction between the magnetic fields surrounding the tubes and coils, the impedence of the tubes and coils, stray capacities, and unbalanced resistances, resulting in uncontrolled oscillations. The feed-back will be more pronounced on some wave lengths than on others, and when tuning is attempted.

Several ideas have been advanced for neutralizing these strays. Grounding of all pieces composing the set to a metal shield has been resorted to. Sometimes the tubes, transformers, etc., are all enclosed in individual metal "pigeon holes," leaving only small openings through which the necessary wires are run. But the shield, alone, is not altogether successful in eliminating troublesome feed-backs. The potentiometer method of producing stability, as shown in figure 415, is usually satisfactory when no tuning is attempted, and in some carefully designed sets, covering a comparatively narrow range of wave lengths, tuned radio-frequency amplification is used, with only the potentiometer type of stabilizer. In one factory-built model, a 30-ohm rheostat is connected in shunt to the primary of the second radio-frequency transformer, and used to maintain a balance between the transformers and offset any difference in the impedence of the tubes.

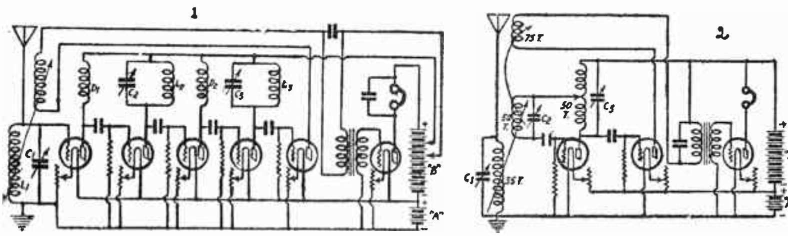


Fig. 419. Two British Receiving Circuits.
(New York Herald Tribune Radio Magazine.)

The potentiometer method of stabilizing wastes some of the energy. It introduces damping into the circuit, which is the reason that it acts as a stabilizer, but on account of this, it reduces the efficiency of the receiver and makes it less selective. Working with the idea of eliminating this resistance, the English experimenters have produced some receiving apparatus differing considerably in appearance from that used in the United States, and they have had remarkable success in reception from American stations on these receivers. Referring to figure 419, the diagram shown at 1 is referred to as "England's latest and greatest radio achievement," by A. Dinsdale, Member Radio Society of Great Britain, in the *New York Herald Tribune Radio Magazine,* of December 14, 1924. He states, "The resonant aerial circuit constitutes the first tuned circuit, and it is followed by the aperiodic circuit composed of the untuned R. F. coupling choke, Dl. Then the tuned plate coupling circuit L2C2, the aperiodic coupling D2, and a third tuned circuit L3C3. The chokes D1 and D2 effectively prevent oscillations, for they are not resonant to the incoming frequency. Aperiodic choke coupling is not so efficient as tuned coupling, and there are two highly efficient and selective R. F. stages, and two stages of mediocre efficiency and no selectivity. The total step-up effect is only equivalent, roughly to that obtainable from three stages of tuned plate R. F., but whereas the latter is unstable and completely unmanageable, the tuned and aperiodic system is perfectly stable and the net effect on the tuning is such that the circuit is highly selective. It is absolutely stable and has no tendency to oscillate."

The diagram illustrated at 2 "is known as the neutral grid method of R. F. coupling. The plate inductance is split, so that a large part of it is included in the grid circuit of the tube. Both sections of the plate inductance are tuned by the condenser C3. By arranging the condenser in this manner the grid of the R. F. tube can be kept absolutely neutral to any oscillations taking place in the tuned plate circuit. No potentiometers or stabilizers are necessary with the result that the efficiency is very high and the selectivity is razor sharp." The numbers against the inductances in this diagram indicate the number of turns.

371. One of the most popular receivers ever designed is known as the *neutrodyne.* This employs a system of neutralizing oscillations in the radio-frequency amplifier which was worked out by Professor Hazeltine of the Stevens Institute

of Technology. Stability is obtained by the use of two small condensers connected as indicated by the heavy lines in figure 420. These condensers neutralize, or balance, the capacity coupling through the tubes of the radio-frequency amplifier,

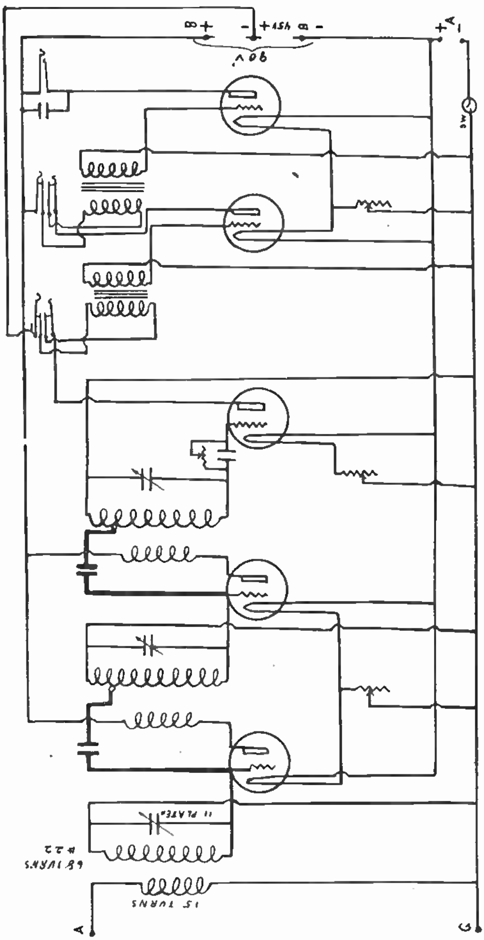


Fig. 420. Wiring Diagram of Typical Neutrodyne Receiver.

when the circuits are tuned for different frequencies. The capacity required to accomplish this result depends upon the capacity between the plate and grid of the amplifier tube with which it is used, and the ratio of the transformer.

With a ratio of transformation of 1 to 1, this capacity is the same as the internal capacity of the tube, which is usually about 10 or 15 micromicrofarads. However, with neutrodyne receivers it is customary to employ radio-frequency transformers with a step-up ratio of 3 or 4 to 1. A formula for determining this, given out by Professor Hazeltine, is as follows:

With N_1 representing the number of turns on the primary of the transformer, N_2 the number of turns on the secondary, C_1 the capacity between the plate and grid of the tube and C_2 the capacity of the neutralizing condenser,

$$\frac{N_1}{N_2} = \frac{C_2}{C_1}$$

The original neutrodyne condensers designed by Professor Hazeltine consist of two pieces of wire inserted inside a small piece of insulating tubing, which in turn is surrounded by a metal sleeve. The distance between the ends of the

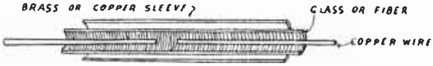


Fig. 421. Cross-Section of Neutrodyne Condenser.

wire may be varied to obtain the desired capacity, in the first place, after which the metal sleeve is moved along over the insulating sleeve for tuning. Some manufacturers

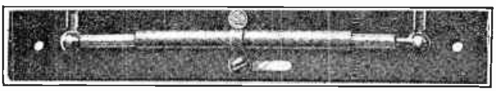


Fig. 422. Fada Neutrodyne Condenser.

licensed under the Hazeltine patent to market neutrodyne apparatus have placed a center tap over this sleeve, to which the connection may be soldered, instead of at the end, if desired, after the correct neutralizing capacity has been found. The rules for accomplishing this are as follows. Tune in a signal, a distant station if possible. Then take the first tube out of the socket, and move the metal sleeve on the first neutrodyne condenser until the signals become very weak, or completely disappear. The dials of the condenser are again rotated, until signals are again heard in the telephones. The tube which was taken out is replaced in the socket, with a piece of paper over one of the filament contact points, so that the filament does not light. If the signals are made much weaker by inserting the tube in the socket, with the filament unlighted, and if they become

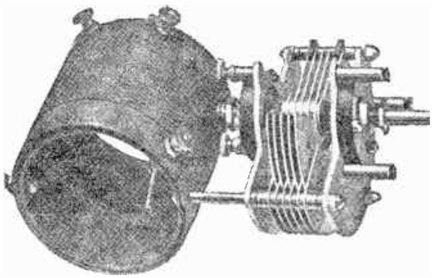


Fig. 423. Radio-Frequency Transformer Mounted on Tuning Condenser.

louder when this tube is removed, the correct adjustment of the neutralizing condenser has been obtained. The same thing is then done with the second tube and second neutrodyne condenser, leaving the first tube, with its filament lighted, in the socket. Or, the neutralizing may be accomplished by means of a buzzer tester unilaterally connected as shown in figure 424 instead of by tuning in an outside station. It should be at least 15 feet away from the receiving set. The filaments of the receiver should be operated on enough current to cause a sizzling noise in the telephones,

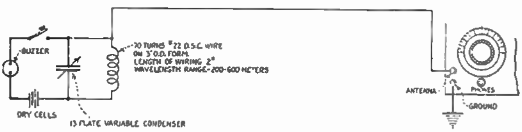


Fig. 424. Buzzer Method of Adjusting Neutrodyne Condensers.

for the neutralizing process. For ordinary operating, they should be adjusted to just below this point. It is not always necessary to proceed according to the above standard instructions for neutralizing. Often, after the process has been completed, the movable portion of the tubular condenser will be found to be in apparently the same position in which it was before going through the process. It is sometimes possible to simply vary the positions of the sliding portions of these condensers by pushing them along with a rubber eraser on the end of a long pencil, using the ear as a guide for obtaining the best result, which is the adjustment at which it is possible to tune the radio-frequency circuits with the variable condensers with a minimum of squealing.

The transformers of neutrodyne sets are of the air-core type, wound over a piece of tubing, and mounted on the condenser as shown in figure 423. In some cases the mechanical supports are also the electrical connections of the secondary windings to the condensers. In the receiver illus-

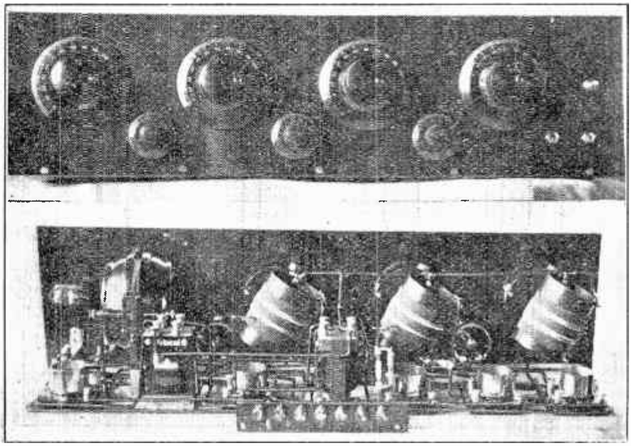


Fig. 425. Photograph of Neutrodyne Receiving Set made by a Construction Class Student in the Loomis Radio College.

trated in figure 425, the secondary was wound first, over a bakelite tubing 2¼ inches in diameter and 3 inches long. It consists of sixty-eight turns of number 22 double silk-covered copper wire. The ends were soldered to brass machine screws, which were used, with small brass strips, to attach the transformers to the condensers in such a manner that they serve as an electrical connection as well, one side being attached to the fixed plates of the condenser, and the other to the movable plates. The primary was wound over this, and separated from it by a double thickness of yellow empire cloth. It consists of 15 turns wound in the *opposite direction,* with the ends brought out to the edges of the tubing and run through small holes drilled in the latter. The wires are secured with sealing wax and empire cloth placed under the ends leading from the primary so that these wires cannot touch the secondary coil at any point. This is necessary, because the insulation of this type of wire is not strong enough to prevent the high-voltage B battery current from jumping from one coil to another and forming a short-circuit. The empire cloth was fastened in place with surgeons' adhesive tape.

The secondary of the first neutroformer has no extra tap, as it serves as antenna coupling. The second and third transformers have a grid tap taken off at the eighteenth turn. It is made by turning a small loop in the wire when winding the coil. These taps must be at the same end of each coil, and sometimes there is a little difficulty in getting this connection just right. If signals are weak, connections to the ends of the coils may need to be reversed.

The neutrodyne receiver employs an *aperiodic,* or untuned primary, for the coupling between the antenna and the first stage. Tuning is accomplished by means of the variable condenser only. The tuning of the secondary circuit, by means of the condenser, affects the wave length of the primary due to the mutual induction of the two coils. The primary coil, being of only a small number of turns of wire, having no variable contact in any way, means that the antenna system is used at approximately its fundamental wave length. In tuning, it is usually found that the condenser dials

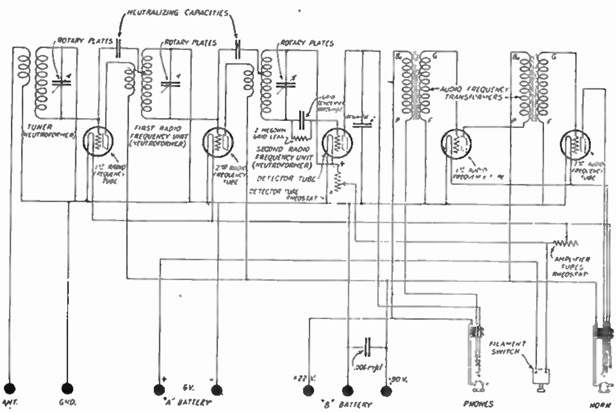


Fig. 426. Wiring Diagram of Fada Five-Tube Neutrodyne Receiver.

will be at the same adjustment for all three "neutroformers." In some cases a geared control is employed, which turns the rotating plates of all three condensers at the same time. This is convenient for people who do not care to bother with much tuning. However, as it is difficult to obtain condensers and coils which have exactly the same characteristics, it is often found that they will not all be tuned in exactly the same manner to get the best results. The coil in the antenna circuit frequently tunes a little different from the others.

Sometimes a variometer is used in the plate circuit of the detector tube of a neutrodyne receiver, making the detector regenerative. If used, the variometer should be of large size, and placed a distance from other parts of the set, under which conditions it gives good results.

Practically all of the neutrodyne receivers are constructed for the purpose of broadcast reception, hence to cover a range of wave lengths around those used for broadcast programs. By using the two stages of radio-frequency amplification, the distance range of the receiver is satisfactory. Under the most favorable conditions this is easily 2,500 miles. A neutrodyne receiver was considered good enough to install on the President's yacht, the Mayflower. By *tuning* the radio-frequency amplifier, in each stage, to the wave length of the station received, maximum sensitivity is obtained from the amplifier, and quite a high degree of selectivity. Each transformer secondary, with its tuning condenser, forms practically a wave trap, which responds to the frequency for which it is tuned.

The neutrodyne receiver gives best results when used with a good outdoor antenna of two or three wires in parallel. While it can be used with a loop, and works well on nearby stations, that is within a few hundred miles, in this manner, it has been found that the loop is disappointing for bringing in the distant stations on the neutrodyne. Some people prefer to have the neutrodyne radio-frequency amplifier constructed as a separate unit, so that it can be attached at will to different types of detector circuits.

372. Various adaptations of the ideas first brought out with the neutrodyne receiver have appeared. In figure 427 we have the same transformer and condenser arrangement as shown in figure 420, but the balancing is accomplished on a different principle. A third winding is placed on the transformer and connected with condensers, as shown at C5 and C4 in the diagram. The theory of this is that an inductive

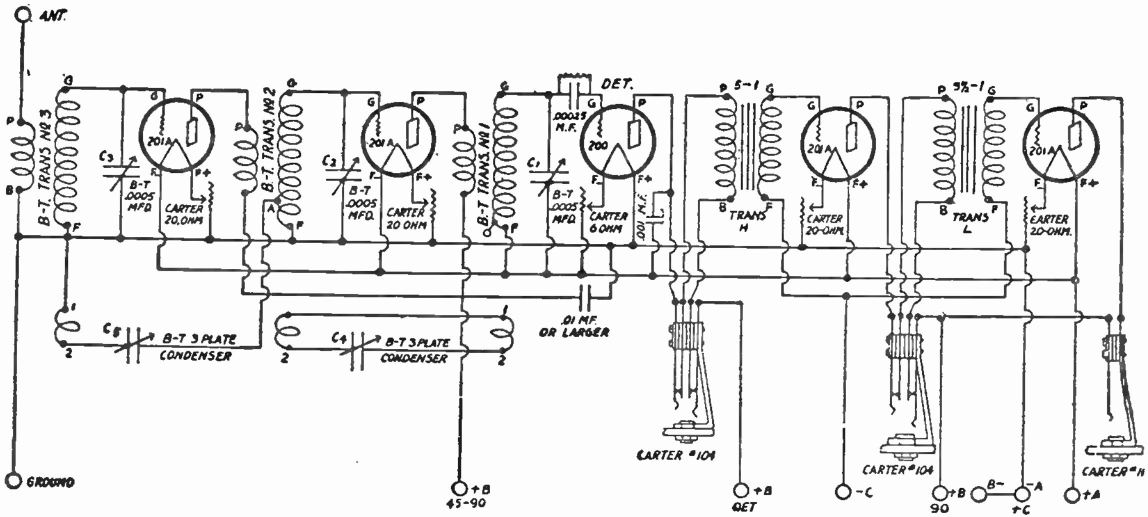


Fig. 427. Five-Tube Receiver with Three-Circuit Transformer Balancing System.
(Bremer-Tully Co., Chicago.)

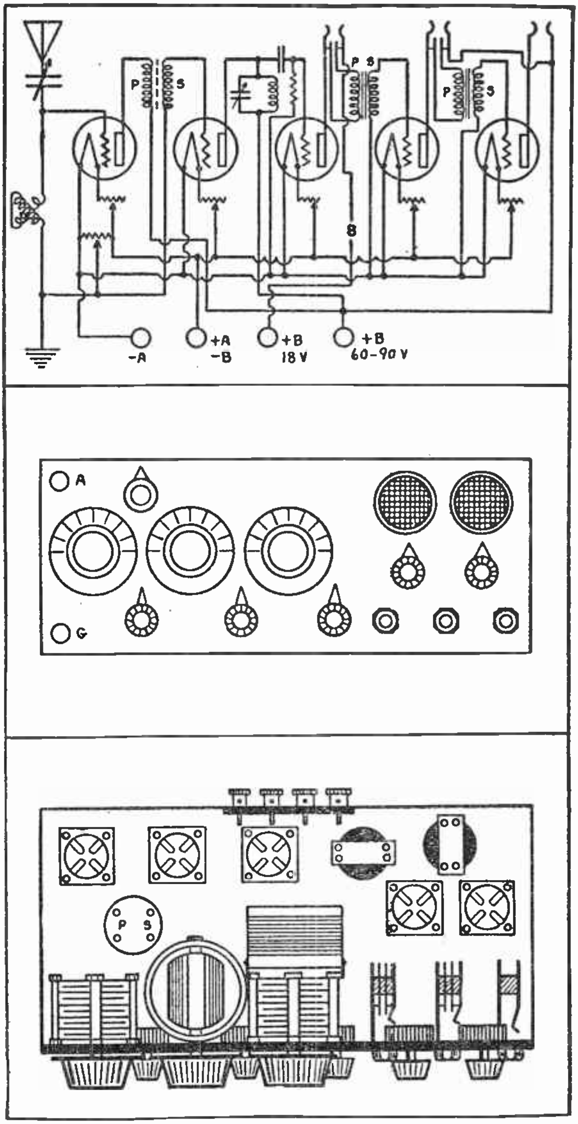


Fig. 428. Wiring Diagram, Panel Layout and Interior Arrangement of a Tuned Radio-Frequency Receiving Set.
(Courtesy of Dr. J. H. Dellinger of the Bureau of Standards, and Lefax Radio Handbook.)

negative feed-back is applied to the first radio-frequency tube and adjusted permanently by means of C5 to balance the inductive and capacity feed-back of the input and output circuits of the tube, thus permitting the circuits to be tuned to exact resonance without oscillation or radiation. The controlling condenser, C5, is mounted on the panel and can be readjusted at any time. "The input and output circuits of the second tube are negatively coupled through inductances controlled by C4, which may be adjusted to prevent oscillation throughout the entire wave length range, or may be adjusted to permit this tube to operate at maximum efficiency, increasing volume and selectivity at the particular wave length of the signal being tuned." Figure 428 shows another adaptation. As can be seen, a variometer is used for tuning the antenna circuit. Another variometer may be added at 8 in the diagram, if it is desired to make the set regenerative.

373. The neutrodyne principle has been successfully added to the "three-circuit" regenerative receiver. An adaption of this is shown in figure 429. This is an illustration of one of the Browning-Drake sets, designed by Messrs. Browning and Drake of Harvard University. Various types of this have appeared, the latest one being the impedence-

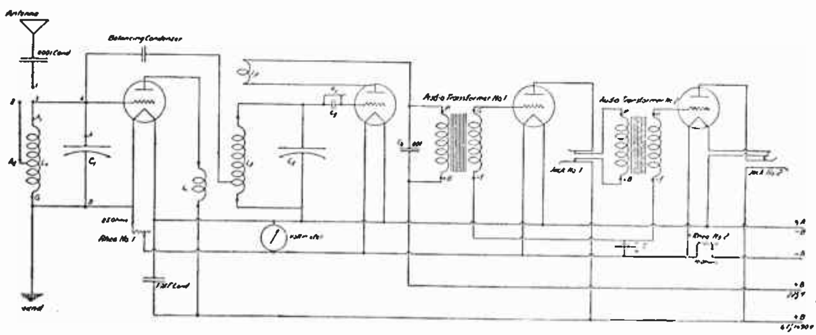


Fig. 429. Browning-Drake Neutralized Regenerative Receiving Circuit. (For a long antenna, connect point 1 to point 2. For a short antenna, connect point 1 to point 3. For a loop antenna, disconnect wire from 3 to 4 and connect loop across A and B.)

coupled apparatus shown in figure 430. In this the Rice method of neutralizing capacity feed-back is used. This achieves a real "bridge," with the upper half of the antenna coil and the capacity of the tube forming one-half of the bridge, and the balancing condenser, with the lower half of the coil forming the other half. The impedence couplers are a National product, made by the Sager Electrical Supply Co., Boston. They have much the external appearance

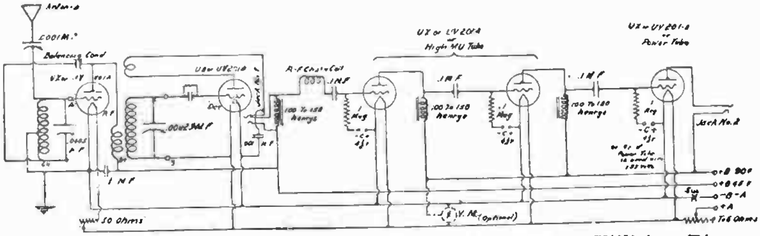


Fig. 430. Browning-Drake Impedence-Coupled Receiver Utilizing Rice Neutralizing System.
(Christian Science Monitor, March 3, 1926.)

of an audio transformer, but have a single winding on the core. With these it is necessary to employ a radio-frequency choke, as shown in the diagram, to keep radio-frequency oscillations out of the amplifier. The tonal quality obtained by this method is excellent.*

374. A receiver in which both radio-frequency and audio-frequency amplification is accomplished by the same tubes is shown, in fundamental form, in the figure 431. A fixed crystal detector is used. The signals are tuned in, used to produce radio-frequency variations through the amplifier tube, passed through the radio-frequency transformer, through the detector circuit, through the audio-frequency transformer, and through the amplifier tube a second time,

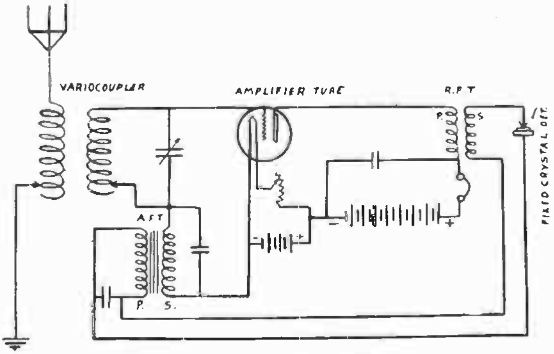


Fig. 431. Fundamental Reflex Receiving Circuit.

*For constructional data for improved Browning-Drake receiver with A. B and C eliminator, see *Radio News*, November, 1926.

producing audio-frequency variations. The tube is responding to different frequencies simultaneously, somewhat as the telephone diaphragm may produce the vibrations of different musical instruments in an orchestra. The telephones are placed so that they may respond to the audio-frequency output of the tube. This is possible, because the radio-frequency fluctuations can pass through the telephones without being heard, and only the lower-frequency variations are audible. This circuit requires careful designing and selection of parts which function properly together. Under such conditions it is very satisfactory and has the advantage of a reduction in bulk for the number of stages used. Also, with a smaller number of tubes less plate current is used, meaning economy in upkeep. The reflex idea may be applied to two, three and four-tube receivers, with either crystal or vacuum-tube detectors. And the neutrodyne principle may be applied to it advantageously. In some factory-built outfits, the vario-coupler is replaced by a compact transformer, having the primary and secondary connected together at one end, and taking the form of the untuned primary arrangement, with the tuning accomplished solely by the condenser shunted across it.

In the diagram shown in figure 433, the second tube, counting from left to right, receives the first impulses

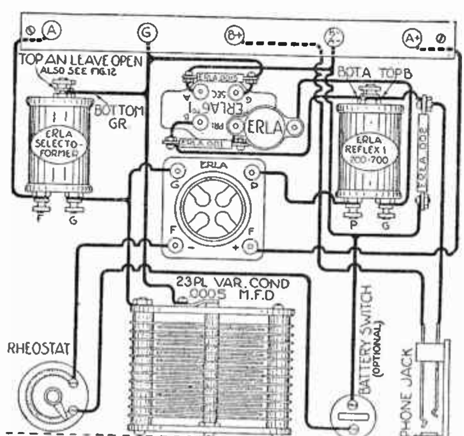


Fig. 432. Erla One-Tube Reflex Circuit with "Selectoformer."

from the antenna. These pass through the following "neutroformer" and tube, the third "neutroformer" and the detector tube. Then the detector-tube output is reflexed through an audio-frequency transformer, and the first radio-first audio-frequency tube. The last stage is straight audio-

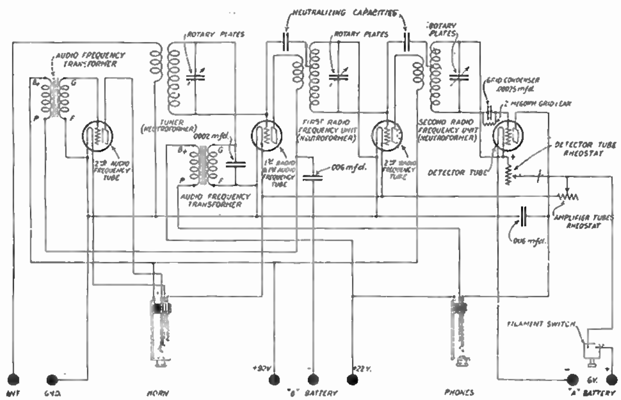


Fig. 433. Fada Reflexed Neutrodyne.

frequency power amplification, not reflexed. Several well-known factory-built receiving sets are constructed on plans similar to figure 433. The reflex is proving very popular for portable apparatus using dry-cell tubes, with cabinets built with compartments for holding the batteries.

Sometimes, when a two or three-stage reflex is set into operation, it becomes uncontrollable, and many strange noises are produced. A tube known as the Sodion, on account of its peculiar characteristics, cannot be made to produce oscillation howls. According to literature of the manufacturer, the Sodion is purely and simply a detector and cannot be used as an amplifier, nor will it regenerate, and therefore no plate tuning or tickler is either useful or required. When the Sodion is connected directly to the tuning circuit, no radiation can take place from the receiving set and thus interfere with the operation of other nearby receivers by causing squeals and howls. When a radio-frequency amplifier is used with the Sodion some interference may be created unless the adjustments are properly made. The Sodion D-21 combines the sensitivity of the gas detector with the stability of the hard tube. It utilizes certain properties of an alkali metal which are responsible for its uniform operation and sensitivity. The third electrode is not a grid and is not interposed between the filament and plate. It is placed behind the filament, is trough-like in shape, and is called the collector. Filament, collector and plate are sealed within a small tube which also contains a small amount of the alkali metal. A heating coil, in series with the filament, is wound around the outside of the small tube. This tube is then mounted within a protective outer shell and sealed into a standard base. When the tube is first lighted, immediate operation will be secured, but its sensitivity will gradually increase for about two minutes, which will, in some cases, make it desirable to slightly readjust the filament current after the tube has been in operation for a short time. The D-21 requires a filament current of approximately .25 ampere and a potential of 5 volts at the tips of the filament. It can be operated on dry cells or storage battery. The resistance if the rheostat used with it should be from 10 to 15 ohms. The Sodion tube is well adapted for

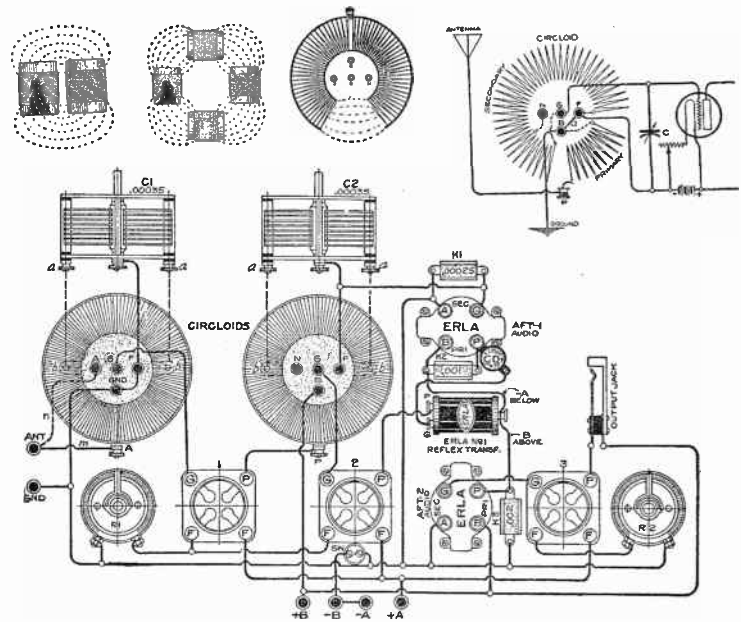


Fig. 434. Circloid-Coil Reflex Receiver.

use as a detector in reflex circuits, where stray oscillations are especially to be avoided.

A type of coil, having no external magnetic field, and called by various names, Toroid, Baloon Circloid, etc., is indicated in figure 434. The drawings at the top illustrate

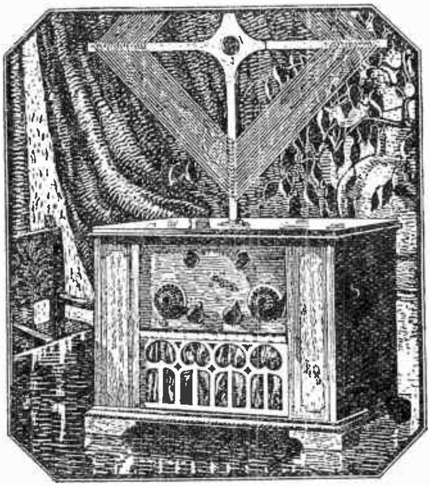


Fig. 435. De Forest Four-Tube Reflex Receiver, D-12, with Loop in Jack at Top of Cabinet.

the magnetic fields between ordinary solenoids wound on tubing, and the field of the coil when bent into a circle. The diagram is a three-tube reflex using Erla Baloon Circloid Coils.

375. During the World War, Major Edwin Armstrong, of the U. S. Army, was faced with the problem of constructing a receiving apparatus which would handle signals of a much higher frequency than had previously been employed by the Allies. The general theory of the performance of the *super-regenerative* receiver developed by Major Armstrong, to meet this need, consists of creating a control of the resistance of the circuit. The following words of Major Armstrong are quoted from an article in the *Proceedings of the Institute of Radio Engineers* in 1922: "If a periodic variation be introduced between the negative and positive resistance of a circuit containing inductance and capacity, in such a man-

ner that the negative resistance is alternately greater and less than the positive resistance, but that the average value of resistance is positive, then the circuit will not of itself produce oscillations, but during these intervals when the negative resistance is greater than the positive, will produce *great amplification* of an impressed emf. The basis of super-generation was the discovery that a variation in the relation between the negative and positive resistances prevented a system which would normally oscillate violently from being self-exciting. The rate of variation in the relation between the negative and positive resistance is a matter of great importance. It may be at sub-audible, audible or superaudible frequency. For modulated continuous-wave telegraphy and spark telegraphy, to retain tone characteristics of the signals, it must be well above audibility; for maximum amplification, a lower and audible rate of variation should be used. In continuous-wave telegraphy, where an audible tone is required, the variation is at an audible rate. The lower the frequency the greater the amplification,

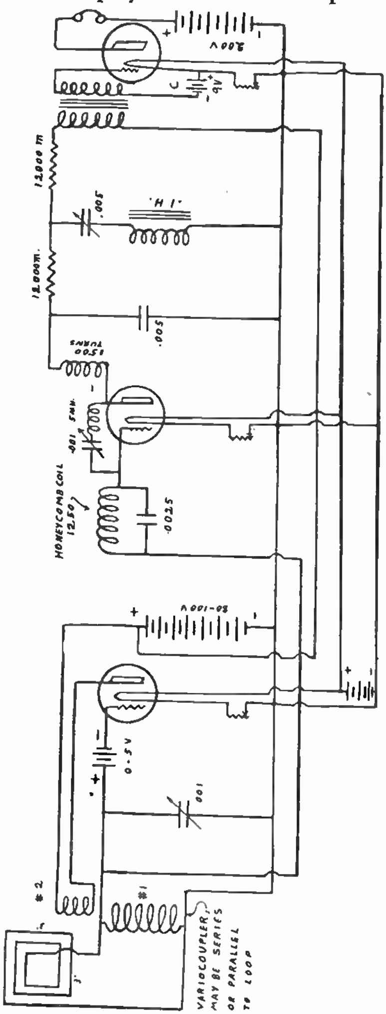


Fig. 436. The Original Armstrong Super-Regenerative Circuit, as drawn on the blackboard during a lecture on the subject by Major Armstrong in New York, in 1922.

and the higher the frequency the better the quality. The free oscillations set up in these circuits by the reaction of the amplifying system continue in these circuits during the interval when the resistance of the amplifier circuit is positive, re-excite the amplifier when the resistance becomes negative, and hence the entire system is kept in a continuous state of oscillation. The effect is most critical and may be produced with most extremely weak couplings between the amplifier circuit and the second tuned circuit. The simplest solution of the difficulty is to perform the function of tuning at one frequency and amplification at another, and this may be adapted to work on either the sum or difference of the frequencies, but when the higher frequency is used care should be taken that it is not near the second harmonic of the local heterodyning current. In the various forms of self-heterodyne circuits a free oscillation of constant amplitude is maintained in the system and the circuit may be considered as having zero resistance, but only for that particular amplitude of current. An external emf. impressed on the circuit always encounters a positive resultant resistance, assuming, of course, that the existing oscillation is stable. This is due to the non-linear characteristics of the tube."

Adaptations of the super-regenerative system have since become very popular, and are generally known as *super-heterodyne* receivers. The idea is to "pick-up" signals of extremely high frequency, or short wave length, which ordinarily could not be successfully passed through several stages of radio-frequency amplification, on account of the necessary inductance of the transformers; to produce a *super-audible* beat note by superimposing locally generated radio-frequency oscillations upon the received oscillations, and to pass this *beat-frequency* through several stages of radio-frequency amplification, in which the transformers are designed for a particular long-wave frequency known as the *intermediate frequency,* after which the *amplified beat* is passed through a regular detector and audio-frequency amplifier. If the signals are those of damped waves, or modulated or interrupted continuous waves, they will be audible in the telephones or loud speaker. *While the frequency of the carrier wave, in the case of radiotelephony, is changed at the receiving station, the modulation is not lost.* When unmodulated, uninterrupted, continuous-wave

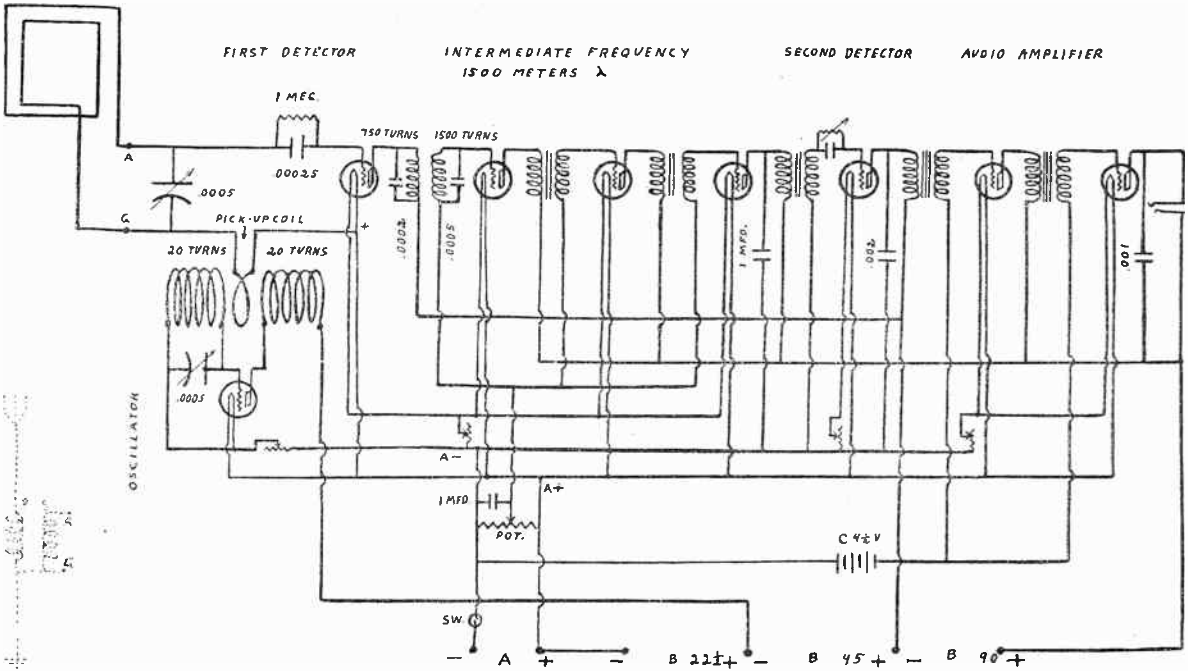


Fig. 437. Wiring Diagram of a Superheterodyne Receiver Designed for Broadcast Reception.

signals are received, a second heterodyne oscillator is employed in the second detector circuit to produce a *second beat* within the frequency range of audibility. This principle has been used in the U. S. Signal Corps since the World War, especially for communicating with airplanes, which usually transmit on rather short wave lengths. The wiring diagram of the standard type of superheterodyne receiver is exactly the same as that of the ordinary multitube radio and audio-frequency amplifier arrangement, with the addition of an extra detector and separate oscillator placed between the antenna and the first tube of the radio-frequency amplifier. Sometimes a greater number of radio-frequency stages are used than in the more simply constructed sets. The condenser in the grid of the first detector rectifies the signal oscillations and those from the local oscillator. As the long wave, or intermediate transformers, are very broad, it is advisable to employ a radio-frequency coupler, or sharply tuned transformer, having its coils shunted by suitable condensers, between the first detector and the first amplifier tube. This is designed to select only the frequency for which the intermediate transformers are tuned, and is sometimes called a filter. Inductively coupled honey-comb coils are often used for this purpose, and may have the same number of turns, or arranged to have a step-up ratio. The intermediate frequency may be anywhere from 1,500 meters to 20,000 meters, the range from 1,500 to 4,500 being the most frequently used for broadcast reception. If a lower frequency is used, long wave code signals may come through, causing interference, or distortion in radiophone reception. The transformers must be carefully matched to exactly the same wave length. Otherwise they may reduce the volume of the signals instead of increase it. By throwing the circuit out of resonance, they act as a choke. Several good makes of transformers manufactured especially for use in superheterodyne receivers are on the market. They can be made outside of a factory, but considerable experimenting may be required before the desired

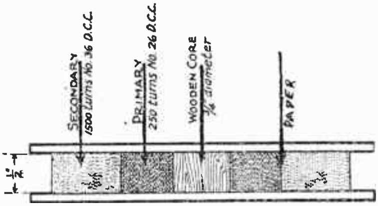


Fig. 438. A Home-Made Intermediate-Frequency Transformer.

results are obtained. QST, for June and July, 1924, contained a compilation of constructional details for the building of superheterodyne receivers, including the intermediate-frequency transformers, gathered from many sources by the editor of that magazine. In some of the factories where superheterodyne intermediate transformers are made, they are matched by placing the primary and secondary in the grid and plate circuit of a vacuum-tube oscillator, so that the secondary of the transformer acts as a tickler coil. The pick-up coil of a wavemeter is then placed in inductive relation to the transformer and its natural period is easily determined.

The coupling between the first detector and the oscillator may be accomplished in various ways. Usually the grid and plate coil of the oscillator are arranged on a supporting frame or tubing, with the pick-up coil arranged mechanically inside of this. The latter may be either fixed or variable. A home-made one which has proved satisfactory consists of 20 turns each, wound in the same direction, for the grid and plate, of No. 22 silk-covered copper, wound over a bakelite tubing 4 inches in diameter, with these coils spaced about half an inch on the tubing. The pick-up coil then is made of a single turn of ordinary round bus-bar wire, placed snugly inside of the tubing, at the center, with its ends soldered to two small binding posts which are fastened about 1 inch apart in the space between the grid and plate coils.

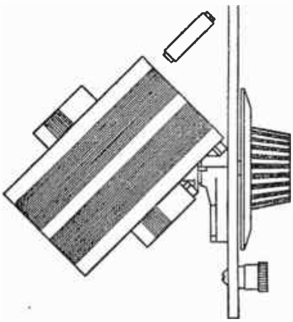


Fig. 439. Haynes Variable Oscillator Coupler.

Tuning is facilitated if the condenser required for tuning the first detector circuit and the oscillator are arranged so that the rotating plates can be controlled by a single dial. This may be accomplished by a pulley arrangement, or two variable condensers with gears, such as the Cardwell, may be mounted so that the shaft of only one of them comes through the panel, and the other one, behind the panel has its gears operated by the gears of the first one.

The purpose of the separate oscillator is to reduce instability of the beat note, which may be difficult to control with the autodyne circuit.

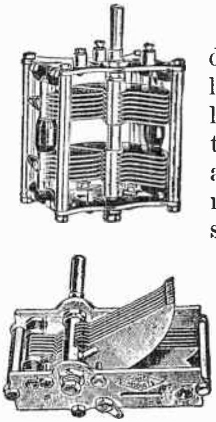


Fig. 440
A Double Condenser and a Geometrically Designed "Straight-Line" Condenser.

Several superheterodyne receivers are designed for use with a center-tapped loop, which forms a typical Hartley oscillator. The ratio of turns on each side of the center tap must be correct or results are poor. When such a receiver is connected to an elevated antenna, the coupler secondary must be tapped to correspond and the terminals connected to the three loop binding posts. Spider-web coils spaced one-half inch, with fifteen turns of number 26 d.c.c. wire for the primary, twenty-five turns for the plate coil and thirty for the grid, have proved satisfactory. They can be mounted inside the receiver cabinet.

376. Resistance coupling has been successfully applied to the superheterodyne receiver. This offers the advantage of amplification independent of frequency, but has the disadvantage of requiring much greater plate power than the transformer types of receivers. A resistance-coupled superheterodyne receiver is installed in Buckingham Palace for the King of England. This is all self-contained, using dry-cell tubes, with the batteries in compartments beneath the main part of the receiver, as shown in figure 445. The antenna system consists of two copper plates, one hidden at the top of the cabinet, and the counterpoise portion hidden underneath the shelf at the lowest part of the console. The wire for connecting this to the receiving set is run up through one of the legs. When the king has this set moved to Windsor Castle, he has a small outdoor aerial and ground attached instead of the copper plates, and this increases the distance range of the apparatus.

The internal capacity of the tubes used in amplifiers affects the natural period of the circuit in which they are used, hence the larger types of receiving tubes require tuned circuits for reception on short wave lengths. On account of this, the resistance-coupled radio-frequency amplifier has been considered more efficient for the longer wave lengths. However, while the amplification is not as great in this type of receiver, it was chosen for the king on account of its simplicity of control. By using the small tubes, with small capacity, the set can be used for broadcast reception.

377. Summing up the advantages and disadvantages of the preceding types of superheterodyne receivers, we find that with the long-wave intermediate-frequency transformers, there is a possibility of long-wave interference; the apparatus, especially if connected to an elevated antenna, will *radiate* oscillations, unless some method designed especially for preventing this radiation is employed; and, on account of the large number of tubes used to obtain the desired results, the apparatus is bulky, costly, and expensive to operate. The resistance coupling requires costly high plate voltage, and it derives its frequency period from the capacity of its tubes, hence low-capacity tubes must be used for short-wave-length reception. On the other hand, the superheterodyne provides great amplification of weak signals of broadcast wave lengths or other wave lengths, if desired. It can be operated successfully on a small indoor loop, even one contained within the cabinet. It is selective, picking out the stations desired and tuning out the others if on other wave lengths. It is a "distance getter," gives a clear tone, and can be controlled with a very few knobs or dials.

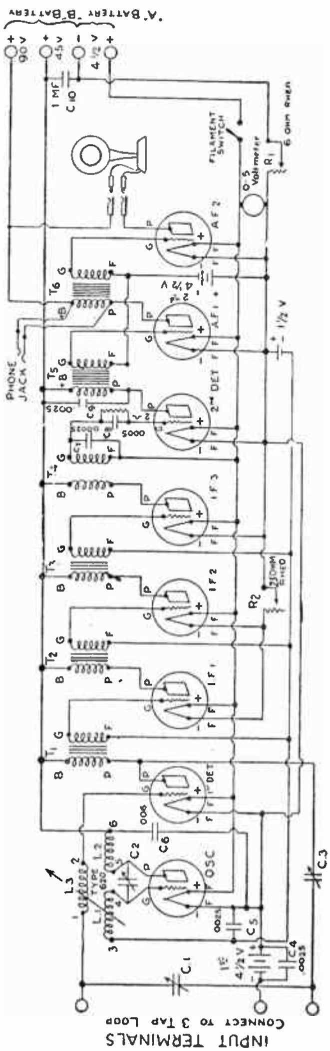


Fig. 441. Circuit Diagram of an Eight-Tube Superheterodyne Using a "C" Battery in the Grid of the First Detector Tube.
(Gerald M. Best Co., San Francisco.)

378. It is not impossible for an oscillating condition to exist in the intermediate-frequency amplifier of the superheterodyne. The potentiometer stabilizer is sometimes used, and the tubes must be kept just below oscillation. The neutrodyne "neutroformer" idea may be applied to the superheterodyne, if the winding of the coils is such as to give the correct period for the intermediate frequency. However, this is an exceedingly bulky arrangement, and unnecessarily complicated in tuning. Some experimenters have obtained good results by connecting neutralizing condensers, of the usual neutrodyne type, between the intermediate transformers of superheterodyne receivers, if they are of the air-core type. This has generally increased the volume. It is also possible to decrease interference from local stations, and increase the distance range somewhat, by using the arrangement indicated in figure 446. This is one stage of straight radio-frequency amplification preceding the first detector of the superheterodyne.

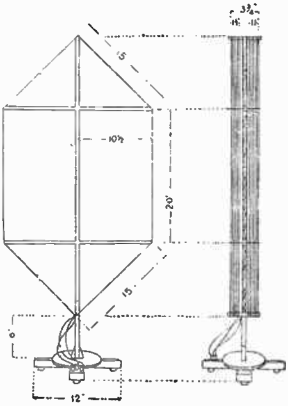


Fig. 442. Three-Tap Loop, Indicated in Figure 441.

379. The reflex idea has been applied to the superheterodyne by Major Armstrong. Incidentally, a non-radiating scheme was devised, and the *second-harmonic* superheterodyne was evolved. The following words of Major Armstrong are quoted from a paper read by him before the In-

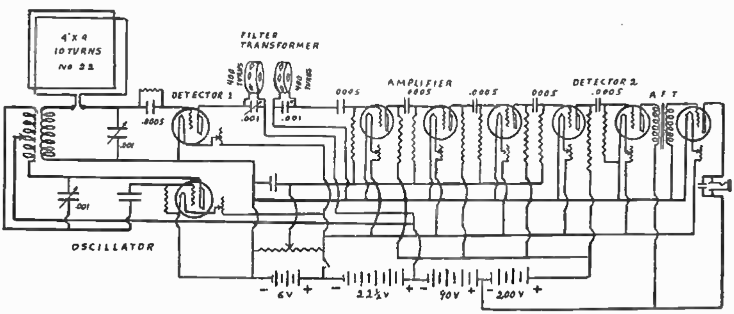


Fig. 443. Resistance-Coupled Superheterodyne.

stitute of Radio Engineers, March 5th, 1924, and published in the *New York Herald Tribune Radio Magazine,* and a Radio Club of America paper, which was published in the July, 1924, *Radio Broadcast.*

"It had been apparent ever since the question of the application of the superheterodyne to broadcasting had been considered, that there were too many tubes performing a single

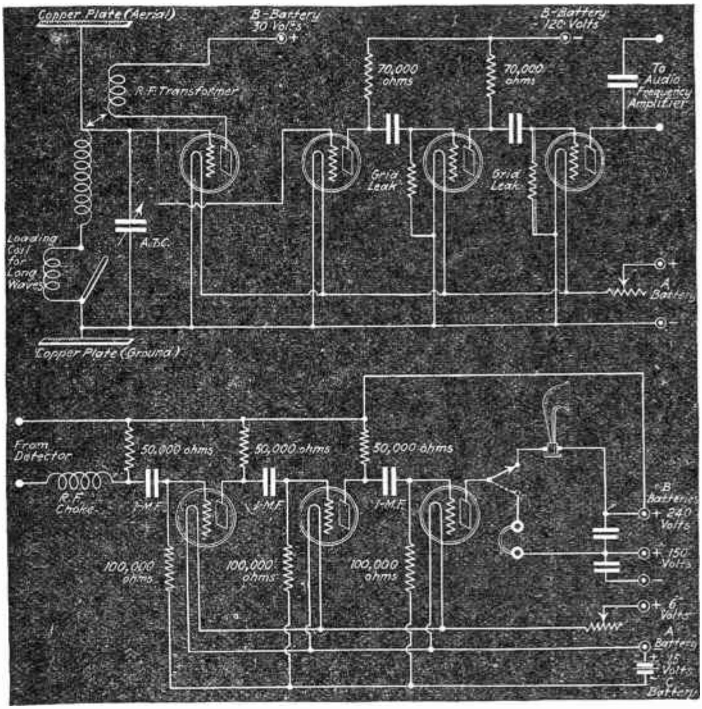


Fig. 444. Circuit Diagram of King George's Receiving Set. (Courtesy Radio World.)

function which were quite capable of performing a double one. First the oscillator was eliminated, by making the first detector tube both oscillate and detect. The set *radiated a strong signal* when connected in this manner. To eliminate this it was necessary to place a high-frequency amplifier in front of the detector-oscillator tube. Another difficulty was encountered. With the detector-tube tuning circuit oscillating, the input circuit was thrown out of tune. Mr. Harry Houck was the first to solve this problem. He suggested that the detector tube be made to oscillate at a frequency equal to *one-half* the frequency the intermediate-frequency amplifier was tuned to. For example: The signal received has a frequency of 600,000 cycles. One-half is 300,000. The intermediate frequency amplifier is tuned to 50,000 cycles. One-half of that value is 25,000 cycles. The difference between half the input and half the intermediate frequency is 275,000. Now, due to the symmetrical action in the tube, any frequency generated in the tube has certain harmonics, and Mr. Houck suggested using the *second harmonic*. The second-harmonic value in this would be 550,000, and this frequency combined with the incoming-wave frequency produced a beat note of 50,000 cycles, which is what was desired to pass through the intermediate amplifier.

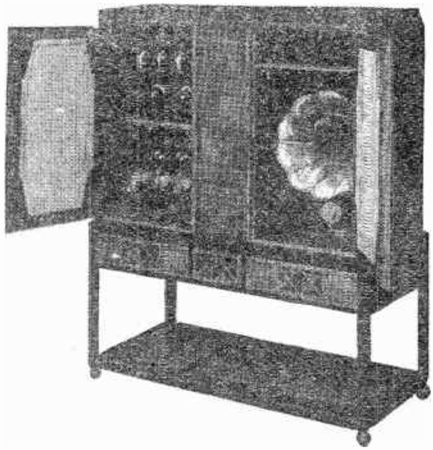


Fig. 445. Photograph of King George's Superheterodyne.
(Radio World.)

Houck proposed to connect two tuned circuits to the oscillator, a simple circuit tuned to the frequency of the incoming signal and a regenerative circuit adjusted to oscillate at such a frequency that the *second harmonic* of this frequency beat·

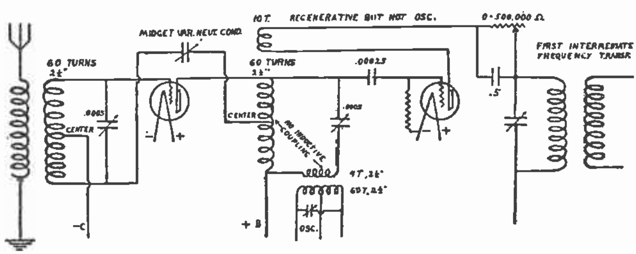


Fig. 446. Superheterodyne with Neutrodyne Radio-Frequency Amplifier.

ing with the incoming frequency produced the desired intermediate frequency. This arrangement solved the oscillator problem and, in addition, practically *eliminated radiation.*

The next step in the reduction of the number of tubes was to make the radio-frequency amplifier perform the function

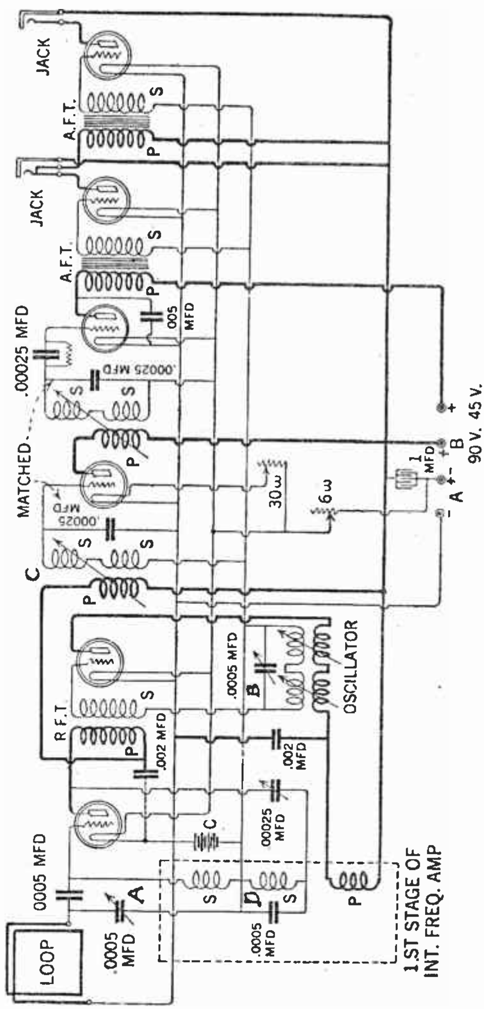


Fig. 447. Wiring Diagram of the Armstrong-Houck Second-Harmonic Reflex Superheterodyne. (Radio Broadcast.)

A is tuned to the incoming signal, B to one-half the incoming frequency plus or minus one-half the intermediate frequency, and C and D to the intermediate frequency.

of amplifying the intermediate frequency as well. This can be done with none of the difficulties inherent in audio-frequency amplification, as the very small amplitudes of voltage handled by the first tube precludes the possibility of the grid becoming positive with respect to the filament.

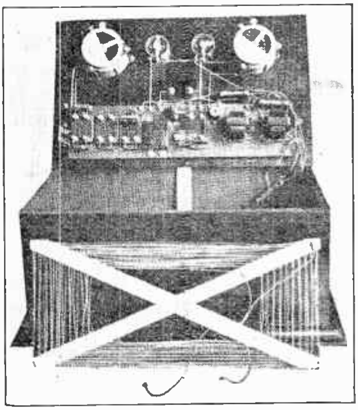


Fig. 448. Interior of the First Second-Harmonic Superheterodyne. (Radio Broadcast.)

In the final circuit the signals received by the loop are amplified at radio-frequency by the first tube and applied to an untuned radio-frequency transformer. The combined signaling and heterodyning currents are then rectified by the second tube producing a current of the intermediate frequency which is applied to the grid of the first tube, amplified therein and passed on to the second stage of the intermediate-frequency amplifier.

Improvements in the design of the intermediate-frequency transformers made it possible to obtain with two stages all the amplification which could be used. On account of the high amplification, signals from local stations overload the second rectifier and introduce distortion. Control of the amount of intermediate amplification is essential. The

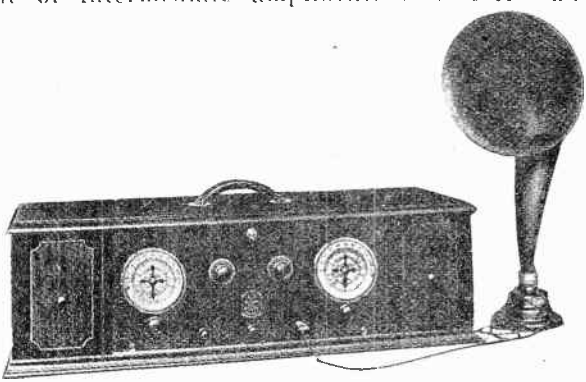


Fig. 449. The Portable Six-Tube Radiola Second-Harmonic Reflexed Superheterodyne, with Batteries and Loop Antenna Contained in the Cabinet.

simplest method appears to be the control by means of the filament temperature of the second intermediate-frequency amplifier." *

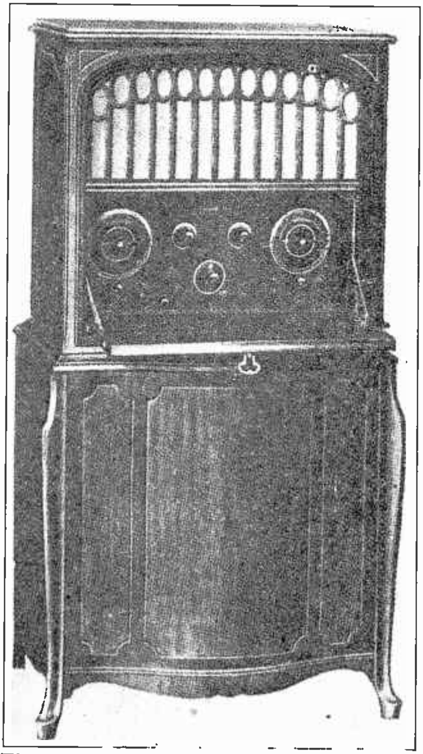


Fig. 450. Luxurious Parlor-Type Radiola. (A loud speaker is built in at the top and a rotatable loop antenna is enclosed in the lower portion of the cabinet.)

The principle of the *electrical bridge* has been applied to the superheterodyne by Jackson H. Pressley, chief radio engineer of the U. S. Signal Corps. This apparatus is the result of over two years of research by Mr. Pressley, in an effort to produce a sensitive short-wave receiver of small bulk and light weight which could be carried in airplanes. The wiring diagram of the receiver is shown in figure 451. In figure 452 a resistance bridge, commonly known as the Wheatstone bridge, is shown at the upper right. At the upper left is an impedence bridge for alternating current, and below is the application of the latter to the oscillator and first detector of the superheterodyne receiver. It can be seen that the detector and oscillator are combined in one tube, which eliminates one tube from the original standard layout. The bridge arrangement combines the oscillation generator and radiation preventer. The separate circuits may be tuned without mutual effect on each other. In practical application, the variable condenser tunes the bridge

*The tubes in this receiver must be matched, that is, must oscillate at same plate voltage, to obtain good results.

circuit to any desired frequency. Following is a list of the parts recommended for duplicating this receiver. Some of the parts, the intermediate-frequency transformers especially, are chosen for compactness and lightness of weight.

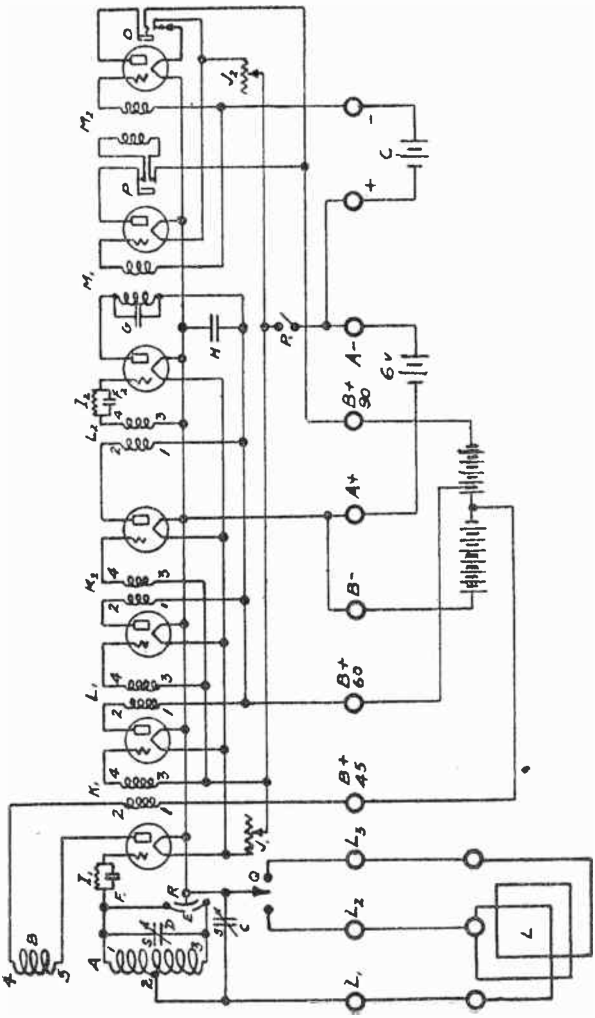


Fig. 451. Wiring Diagram of the U. S. Signal Corps' Superheterodyne, Designed by Jackson Pressley. (New York Herald Tribune Radio Magazine.)

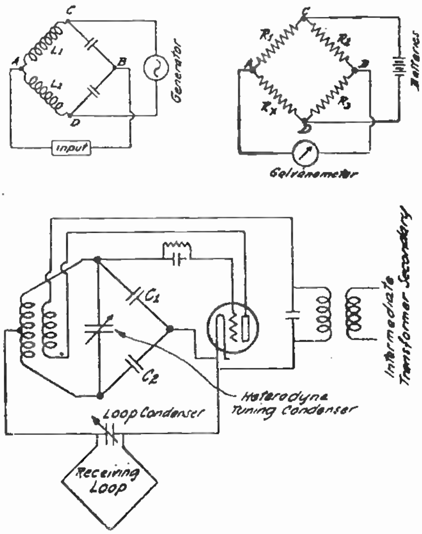


Fig. 452. Development of the Pressley Impedence Bridge Superheterodyne.
(New York Herald Tribune Radio Magazine.)

The completed set goes into a cabinet 7×6×18 inches.

1 7×18-inch Bakelite panel, drilled and engraved.
1 Sangamokit, consisting of one oscillator coil, two iron core and two air core transformers.
1 "X" Laboratories, .00007-mfd. balancing condenser.
1 "X" Laboratories .0005-mfd. Vernier condenser.
1 "X" Laboratories .0005-mfd. plain condenser.
1 "X" Laboratories dial to match.
1 "X" Laboratories 6-ohm rheostat.
1 "X" Laboratories 15-ohm rheostat.
1 Benjamin seven-tube gang shelf.
1 Benjamin grid leak panel.
1 Benjamin battery switch.
1 Pair Benjamin brackets.
1 Thordarson 6:1 audio transformer, first step.
1 Thordarson 2:1 audio transformer, second step.
1 Pacent double circuit jack, No. 63, first step.
1 Pacent single circuit fil. control, No. 65, second step.
2 Dubilier .00015 mfd. micadons, type 601-G.
1 Dubilier .005 mfd. micadon, type 601.
1 Dubilier 5-mfd. micadon, type 656.
1 ¼ megohm grid leak (first tube detector and oscillator).
1 two megohm grid leak (second detector).
1 jack switch (Carter No. 3 or Yaxley No. 30).
1 loop (Portena or Marion).

(See New York Herald Tribune Radio Magazine, February 8, 1925, for Pressley Superheterodyne data.)

380. A different application of beat production to reception of signals is shown in figure 453. This apparatus is named the ultradyne, by Mr. Robert E. Lacault, engineer of the French Signal Corps, who developed it. The ultradyne receiver uses intermediate transformers, and a detector for reducing modulated signals to audibility, but the part of the circuit corresponding to the first detector and oscillator of the superheterodyne is quite different. The first tube, which in the superheterodyne is called the first detector, and which functions in producing the superaudible beats, is called a modulator. In describing this circuit Mr. Lacault says: "No pick-up coil and grid condenser are employed in the ultradyne circuit and no B battery is connected to the modulator tube. The plate filament space of the modulator tube acts as a resistance in the circuit. In this arrangement the plate of the modulator tube is supplied with high-frequency current by the oscillator, the former being active only during half of each cycle when the plate is positive. This produces a change of plate filament resistance which varies from practically infinity to about 20,000 ohms, during each half cycle of the oscillator current when no signal is being received. *When the grid potential of the modulator tube is varied by incoming signals* tuned in by the circuit L′ C′ *the lower resistance value is varied above and below the amount mentioned with various degrees of amplitude according to the phase relation between the incoming signal and local oscillations.* This produces a beat note which is amplified and detected. An advantage of this system is that, no matter how small the amount of received energy, a response in the circuit is produced. In order to obtain greater sensitiveness and amplification, one may use regeneration in the circuit of the modulator tube by merely connecting a feed-back coil in the plate circuit and coupling it to the grid circuit of the same tube as shown in the illustration. This produces great amplification for the reception of weak signals and is quite easy to adjust after a station is tuned in."

The radio-frequency transformers used in the ultradyne receiver are of a different design from those employed in the regular superheterodyne. They are so constructed that they amplify at one wave length only. The band of frequencies amplified by the ultraformers is just wide enough to avoid

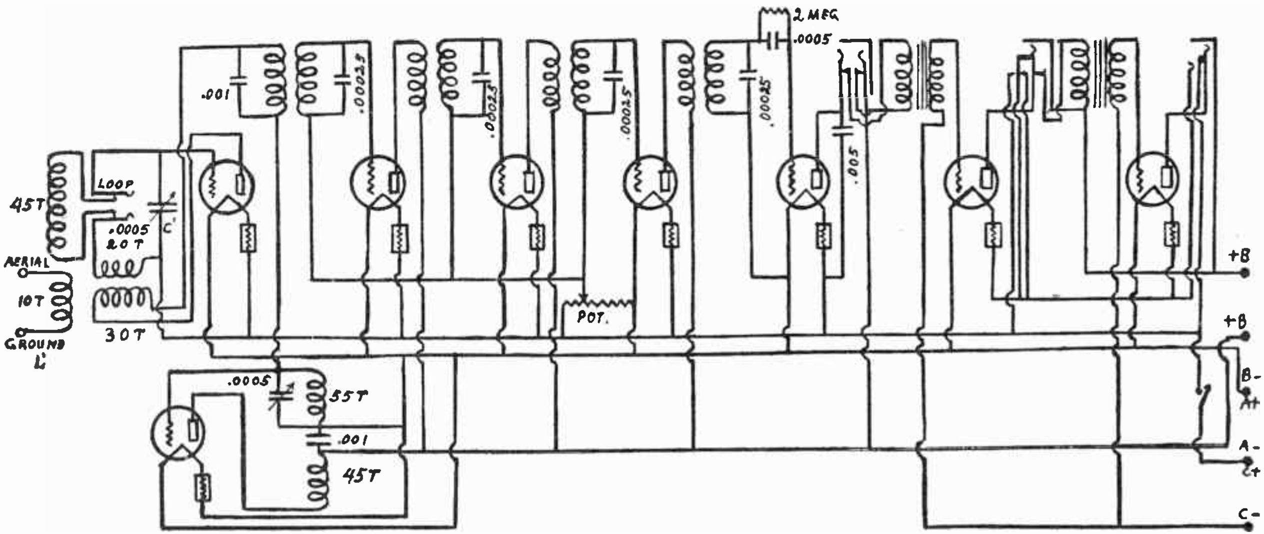


Fig. 453. Circuits of Ultradyne Receiver.
(Phenix Radio Corporation.)

distortion of radiotelephone signals, but they are, nevertheless, sharp enough in tuning to provide the necessary selectivity. The first ultraformer connected between the plate of the modulator tube and the grid of the oscillator tube is of a slightly different construction, the primary being shunted by a small fixed condenser to tune it exactly to the proper frequency. It is important that the capacity of this fixed condenser be exactly .001 mfd. as otherwise the frequency of the input circuit would be different and the amplifier would not operate as efficiently as it should.

In the diagram "Amperites" are shown in series in the filament circuits instead of rheostats. The latter could easily be substituted if desired.

381. In the White House, in Washington, a superheterodyne receiver is installed for the use of the President. This consists of the receiver proper, which contains six dry-cell

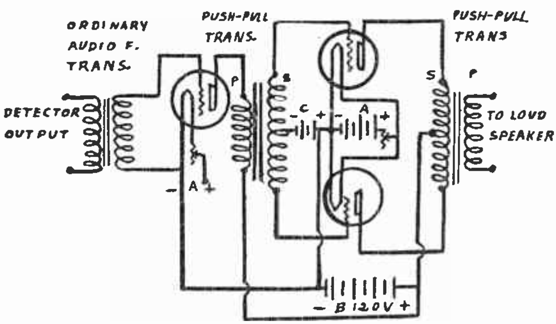


Fig. 454. Three-Tube Push-Pull Amplifier.

tubes, and an additional three-tube "push-pull" amplifier. The apparatus is built in a mahogany table-cabinet, on wheels, so that it can be moved from room to room if desired. The antenna system consists of a folding loop, which disappears in the back of the cabinet when not in use.

The push-pull amplifier is used to obtain additional power for operation of the loud speaker. Some loud speakers require more power than others, and extra amplification calls for special design to avoid distortion. This may be achieved by connecting the tubes as shown in figure 454, where the two tubes in the last stage of amplification use alternately each half of the voice-frequency alternating current in the circuit. The first stage in figure 454 is similar to that in other amplifiers. Special transformers having split primaries and split secondaries, are manufactured for use in this type of amplifier. Ordinary audio-frequency transformers may also be used, if connected as shown in figure 455. The push-pull amplifier was patented by E. H. Colpitts,

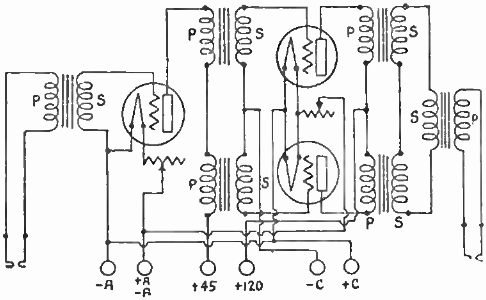


Fig. 455. Push-Pull Amplifier, Using Six Ordinary Audio-Frequency Amplifying Transformers.
(Radio Lefax.)

of the Western Electric Co., in 1915, but public interest in it has been comparatively recent. It was designed primarily for use on land telephone lines, "to improve the quality of transmission by producing in the output circuit electric waves free from distortion with respect to the input waves." The use of the additional tubes and transformers does not increase the amplification appreciably, but makes it possible to use, without distortion, a number of stages which otherwise would be impracticable. The last transformer has a step-down ratio, that is, it is inverted, having the greater number of turns of wire in its input coil, giving increased *current* for the operation of the loud speaker. The action of these transformers is the same as that described in the full-wave self-rectifying tube-transmitter circuits. The plate currents through the push-pull transformers are in the opposite direction, and due to the balancing effect of the magnetic fields in the two transformers, any unsymmetrical action due to the distortion present in each tube individually, is smoothed out. The transformers must be exactly alike or this will not be the result. The transformers constructed especially for use in this type of amplifier are more likely to give satisfactory results than the use of the ordinary transformers as shown in figure 455, although the latter may be made to give fairly good results.

382. Many so-called new circuits appear from day to day. Fundamentally, however, there are only a very few possible receiving circuits. All of the others are founded on these, with adaptations, combinations, and special frills which do not entitle them to the name of a separate circuit. The qualities aimed at in these various designs are *sensitiveness to weak signals, amplification without distortion, elimination of locally produced squeals, prevention of radiation, and simplicity of control.* Also, *economy* in outlay and operation, other things being equal, is an important point.

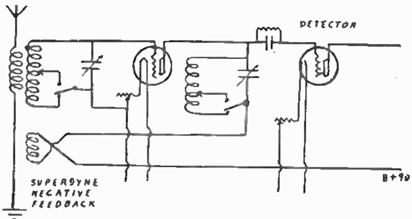


Fig. 456. Superdyne Amplifier.

What has become known as the "superdyne" circuit is an adaptation of the tickler coil to the problem of neutralizing stray capacities in radio-frequency amplifiers. If a tickler coil is connected in the wrong way for producing oscillations, oscillations are prevented. Hence, if oscilla-

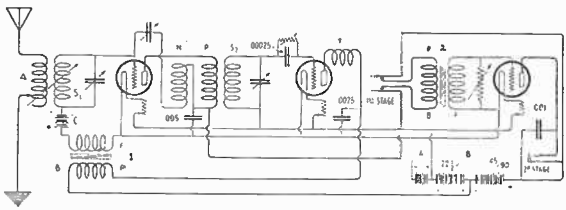


Fig. 457. Wiring Diagram of the Roberts Receiver. (Radio Broadcast, August, 1924.)

tions are *not* desired, connect a tickler coil "backwards." A reversed, or negative magnetic feed-back is the result, and we have an effective neutralizing agent.

An interesting combination is shown in figure 457. This is primarily a reflex set, with one stage of radio amplification, detector, and one stage of reflexed audio-frequency amplification. An additional stage of audio is added, to be plugged in or out as desired. The coils in the first Roberts sets were wound on spider-web forms, and mounted on the condenser, as in the neutrodyne receivers. Some of a later type are basket wound over hollow rings of white celluloid. The movable coils are mounted so as to vary the coupling by moving them sidewise across the surface of the fixed coil, not touching them, of course. The coils are all wound in the same direction, either all clockwise, or all counter-clockwise. In figure 457, A is the antenna coil, which is tapped. S_1 is inductively coupled to it, so that it may be varied in the manner described. P is the primary of the radio-frequency transformer, which is also a spider-web coil. N is a neutralizing coil, wound on the inside of the spider-web, on the order of the Reinartz coil. In series with this is a small two-plate variable condenser, completing the "neutrodyne" part of the apparatus, and neutralizing the capacity between the grid and plate of the tube. T is a spider-web tickler coil, inductively coupled to S_2, making the detector circuit regenerative. B P F_1 is an audio-frequency transformer, reflexing the detector output back into the first tube for the first stage of audio-frequency amplification, and P B F_2, the second stage of audio amplification. Variable grid leaks are used, one shunted across the usual grid condenser, and the other across the secondary of P B F_2. When this receiver is properly constructed it proves quite successful, in spite of its hybrid makeup. It is non-radiating, on account of the amplifier standing between the antenna and the regenerative detector.

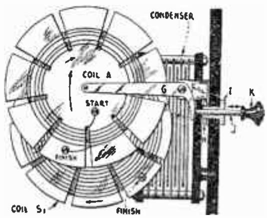


Fig. 458. Manner of Mounting Coils in Roberts Receiver.

An interesting application of resistance control of the impedence of the plate circuit of a radio-frequency amplifier is shown in figure 459a. This is the wiring diagram of the Zenith receiver with two stages of radio amplification. A 2,000-ohm rheostat is in series with the plate of the first tube, and used to maintain a balance between the impedences of the two radio-frequency tubes, thus preventing oscillation of these tubes. The most noticeable difference between tubes appears to be in their drawing a different amount of plate current. The coils are mounted on the condensers, with a space left between two sections of the secondary, as shown in the diagram. The primary is then arranged in two sections, part stationary, and the other portion mounted on the condenser shaft, and rotating inside the secondary with the rotating of the condenser plates. This rotor in the plate circuit opposes the coupling between the fixed portion and the secondary for short wave lengths, and increases this coupling on longer wave lengths, overcoming one of the chief

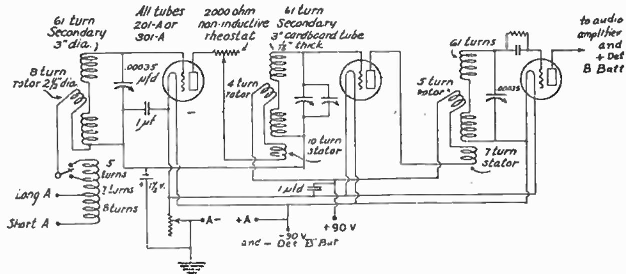


Fig. 459a. Circuit Diagram of the "Super-Zenith X."

difficulties encountered in the development of tuned radio-frequency amplifiers.

This receiver, as shown in figure 459b, is equipped with a "battery eliminator," consisting of filter condenser and coils, for operating the set directly from an alternating-current power line. Provision is made for using the batteries if preferred.

Many of the standard receiving sets on the market change but little from season to season, except for a gradual improvement in cabinet work. For picnics and camping parties, portable receivers are in demand. It is not difficult to arrange a receiving set so that it can be slipped into a traveling case, or out, as desired. Receiving sets installed in *automobiles* may be of the portable type, or more permanently installed. The superheterodyne receiver has proved popular for this purpose. It may be used with dry-cell tubes throughout, or with dry "B" batteries, and a storage battery for lighting the filaments. It is not wise to employ the automobile storage battery for this purpose, as there is sure to be some noise from the spark plugs. The antenna must, of course, consist of some type of loop. In some cases it takes the form of a horizontal loop arranged inside the top of the car. The ground is generally a soldered connection to the steel body, giving a capacity ground to the earth. This is necessary as no direct connection can be made on account of the insulating quality of the tires. A good mechanical arrangement for carrying a receiving set in an automobile is to suspend it on stout springs from each corner of the cabinet, to a strong wooden framework which has been secured to the back of the front seat. A compartment for batteries may be provided underneath if desired.

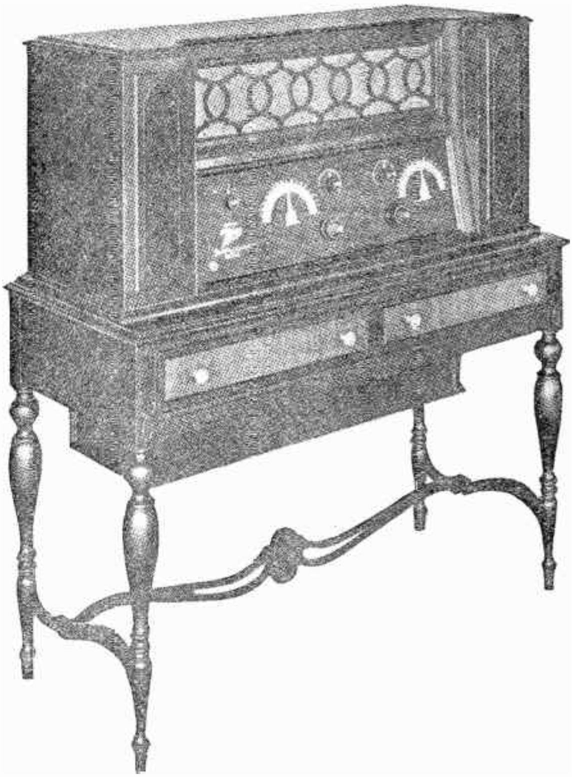


Fig. 459b. Super-Zenith X.

Some types of coils are constructed to offer the least possible obstruction to the magnetic lines of force, and the least resistance to the electric current. These are often referred to as *"low-loss" units*. *"Pig-tail"* connections are made to prevent electrical loss through wiping contacts, such as are made by condenser shafts, etc. Binding posts and screws are often used for making connections in the wiring of the circuits, but these are soldered, after being put into place and tested, as a joint which is soldered properly always gives better contact than a merely mechanical connection.

383. Considerable interest was aroused by the announcement of a vacuum-tube receiving set which worked "without a B battery." Upon investigation this was found to make

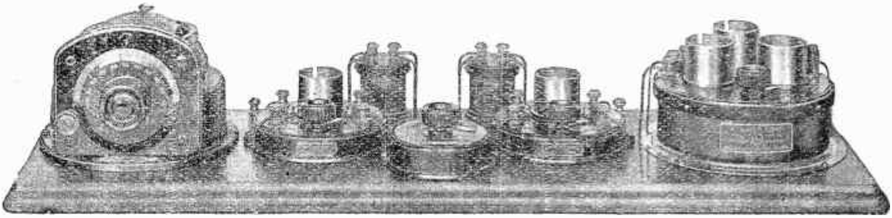


Fig. 460. Atwater Kent Five-Tube "Straight Radio-Frequency" Receiver, made up of various units mounted on a board.

use of the positive side of the filament battery for obtaining a positive condition of the plate of the tube, and an additional grid, also attached to the positive of the "A" battery, which assists in reducing the resistance of the tube. Until tubes having different characteristics than those on the market are produced, this low plate voltage is not expected to give very satisfactory results. However, the four-electrode tube, which is not new, by the way, it having been associated with some of the earliest vacuum-tube research work, has found new applications. In figure 463, A is a simple regenerative receiving circuit employing the "solodyne" principle, without "B" battery. B is a circuit with "B" battery in series with the coiled wire G_2. This makes practically a plate of G_2, and P functions as an additional grid, affording a return path for the negative electrons which are assisted over to it by the positive grid. In this circuit a radio-frequency transformer is indicated as P and S, and the telephones are connected in series with the secondary of an audio-frequency transformer. It can be seen

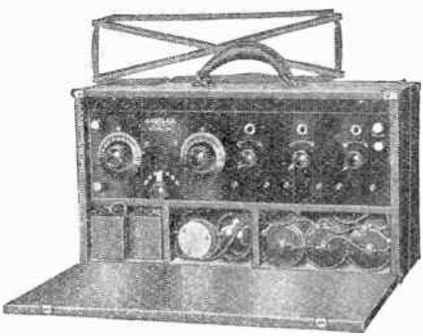


Fig. 461. Crosley Portable Receiver, Showing Neat Arrangement of Compartments for Batteries and Head Phones.

that much more is accomplished here with a single tube than is usual with the more familiar three-electrode tube. At C is shown the circuit of *a receiver which is manufactured by the English Marconi Company for use on seagoing vessels in their service.* Here the tube is acting simultaneously as detector and radio and audio-frequency amplifier. The radio-frequency transformer and secondary are *tuned* by means of taps, as shown. The audio-frequency amplification is reflexed. The potentiometer across the filament battery acts as a stabilizer.

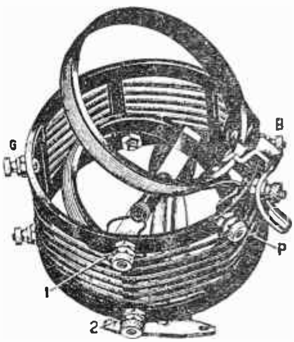


Fig. 462. Three-Circuit "Low-Loss" Tuner.
(Bremer-Tully.)

384. The "new" short-wave receivers which are creating so much interest are merely adaptations of the familiar circuits, with inductance and capacity chosen for a higher frequency than was formerly used. Figure 389 is a circuit diagram of a simple 10-meter receiving apparatus.

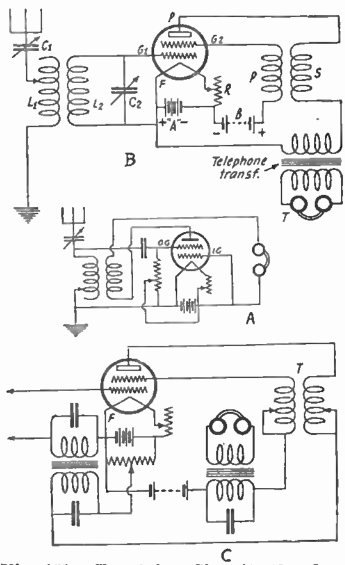


Fig. 463. Receiving Circuits Employing the Four-Electrode Tube.
(Radio News, November, 1924.)

Figure 464 shows front and rear views of a short-wave receiver, a circuit diagram of which is given in figure 333b. While this is not the same set in use at station 3BKC, it is a similar set, and was made from the same specifications by a student in the Loomis Radio College. To make the receiver cover the broadcast band a 13-plate condenser was used instead of the 5-plate at C1 and C2, figure 333b. Every type of loss was reduced as much as possible. At the top of the panel the frame screws of the condenser were loosened to make connections to the binding posts into which the antenna inductance is plugged. The grid condenser is also fastened to a frame bolt, and the lead to the detector tube socket is only one-half inch long, this being the longest lead in the oscillatory circuit. When the 13-plate straight-line condenser is used for covering the broadcast waves, it tunes rather broadly, but it is necessary to use an 80-1 geared vernier dial to separate the stations on

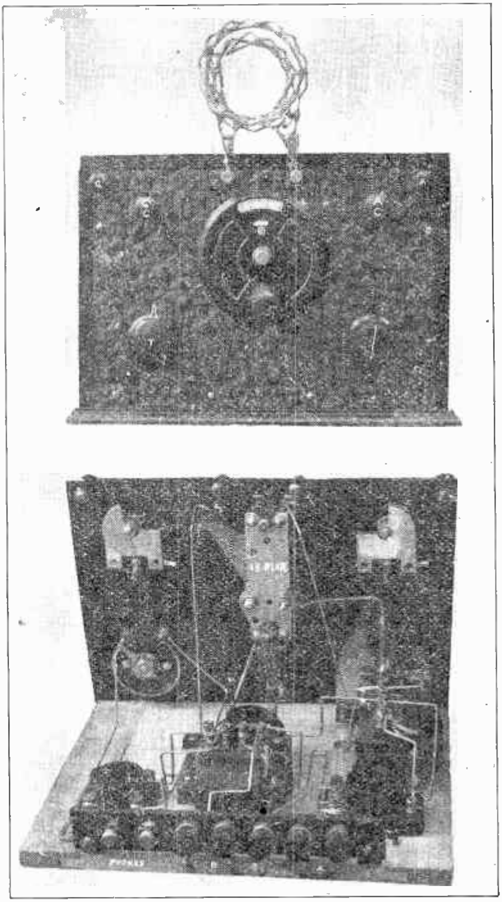


Fig. 464. Short-Wave Regenerative Receiver.

low wave lengths. Different coils are plugged in for different bands as follows:

	L1	L2
40-meter band	5	9-10
80-meter band	8	24-25
10-meter band	2	4-6
Broadcast band	12-20	50-75

The log of this receiver includes some foreign stations on the short-wave-length bands.

385. While storage and dry-cell types of receiving sets can hardly be completely replaced by receivers operated on house current, it is obvious that under certain conditions the use of the house current is more convenient. Figure 465 is a diagram of a detector and push-pull amplifier patented by John F. Farrington, assignor to the Western Electric Co.

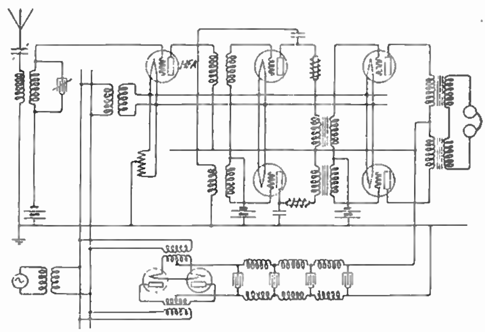


Fig. 465. Wiring Diagram of Receiver to be Operated on Alternating-Current Power Supply.

The outstanding achievement in broadcast reception for the year 1926 was the sudden development of the "*A-B-C eliminator.*" This came after several years of slow and patient experimenting. The B eliminator appeared first, but was soon followed by the A and C eliminator. The fundamental parts of an alternating-current B eliminator, which is the type most used, are a transformer, rectifier, filter and voltage regulator. This sounds simple, but these parts must be *exactly right.* It cannot be said that the first B eliminators were very encouraging. Among the difficulties encountered were the ever-present alternating-current hum, effects of line surges when loads along the line were changed, and the inefficiency of the early rectifiers, which did not pass sufficient current for the multitube receivers. However, later models showed great improvement in filter design, and more efficient rectifiers, meeting with complete success.

Various types of rectifiers are found in these eliminators, chemical electrolytic rectifiers, tubes with filaments and

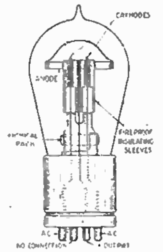


Fig. 466a. Raython Type BH Filamentless Rectifier Tube. (Made to fit standard receiving-tube socket.)

plates, connected for half-wave and for full-wave rectification, but the best of them employ a filamentless rectifier tube with a chemical pack.

Figure 466b is an illustration of a simple half-wave B eliminator. This was home-made, and intended to be used with the filaments connected in parallel and lighted from separate batteries. A Thordarson transformer, type T-129, was connected as shown. This has a secondary rating of about 700 volts. A fuse was connected in series with the primary, as a protection, in case of accident, and a lamp used as a resistance, the current being varied by inserting lamps of different power rating. An Amrad S rectifier tube was placed in the secondary and mounted in a Mogul base, as this tube will not fit the standard sockets. R_1 was made of two 10,000-ohm lavite resistance units connected in series, with the filter circuit connected across one of them. The filter consists of L, which is the secondary of a Ford spark coil, and two Amrad electrolytic condensers, having a capacity of about 20 microfarads each. The usual three connections are provided for the negative "B," positive, 22½ to 45 volts for the detector and positive 90 for the amplifier

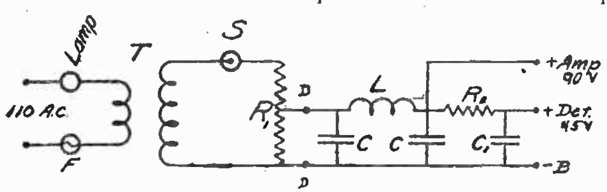


Fig. 466b. Home-Made Battery Eliminator for Direct or Alternating Current. (New York Herald-Tribune Radio Magazine.)

tubes. A second resistance, R_2 is used to reduce the voltage for the detector tube. 100,000 ohms were used for this purpose, but it is suggested that this be made variable. C_1 is a 0.5 microfarad condenser. The same filter circuit may be used for eliminating the hum of a direct-current supply line, for use on the plates of vacuum-tube receiving sets, omitting the transformer and connecting the leads to points D D, with the addition of a fuse at this point. Condensers of 2 microfarads capacity may replace the larger ones, when used on direct current. A lamp may be placed in series with the choke coil in this also, or a variable resistance placed in series with the amplifier tap.

Figure 466c is a typical circuit of a modern A-B-C eliminator. It is designed for operating from five to eight UV-199 tubes with their filaments connected in series. A Raytheon BH tube is used.

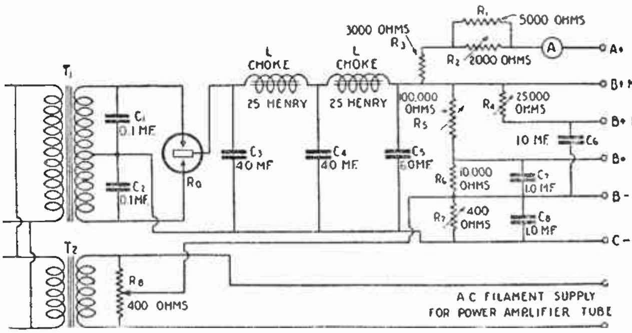


Fig. 466c. Modern A-B-C Eliminator Circuit.
(Radio News, October, 1926.)

The transformer is designed to deliver 350 volts on each side of the tap on no load; and the secondary windings, rectifier, chokes, etc., designed to pass 85 milliamperes. The law of series resistances applied in this manner makes it possible to light the 199 tubes from the plate voltage supply by employing additional regulating resistance. T_2 provides .5 ampere at 5 volts for the filament of a power tube, for operating a loud speaker at greater volume. This is "raw a.c."

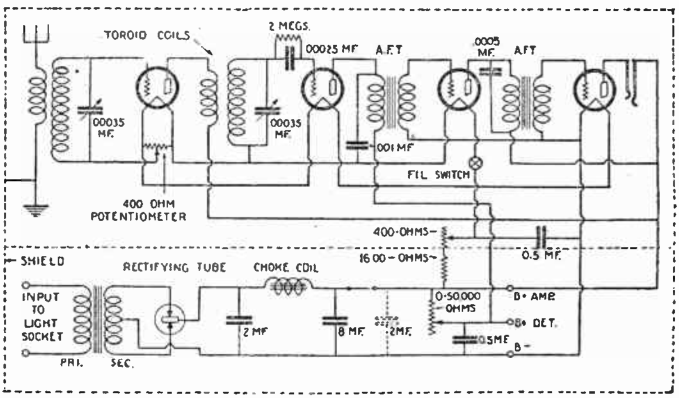


Fig. 466d. Circuits of Batteryless Receiver with Filaments in Series.
(Radio News, August, 1926.)

Figure 466e shows connections used for the RCA voltage-regulator tube, UX-874, which has the property of holding a drop of 90 volts across its elements regardless of current.

In the B eliminators the "C" voltage is obtained by a tap through a resistance. The "A" voltage may be obtained as shown in figures 466c and 466d. In many combination "power units" the filament power is supplied by storage batteries arranged for a permanent trickle charge.*

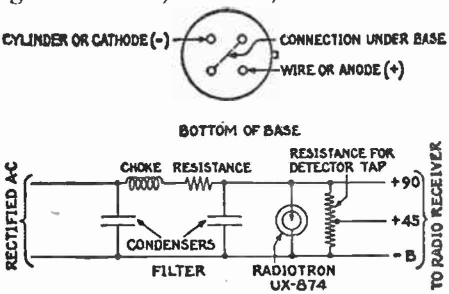


Fig. 466e. Circuit Using UX-874 Voltage Regulator.

Figure 468 is a set consisting of a crystal detector and two stages of audio-frequency amplification, for use in "wired-wireless" reception. The filaments are lighted from the direct-current power line which carries the vibrations of voice or music from the transmitting station. In the earlier types of this receiver the plates were supplied with power from dry-cell batteries, but in the later types this also is obtained from the lighting circuit upon which the modulation has been impressed.

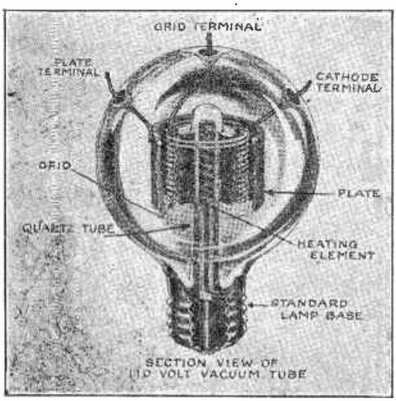


Fig. 467. A Radio Receiving Tube to be Used on a 110-Volt Power Line.
(*Radio News*, February, 1925.)


Fig. 468. A Receiver for "Wired Wireless."
(Radio Broadcast.)

*See QST, February, 1926, article by R. S. Kruse, on Battery Substitutes. Also QST August, 1926, for factory-built eliminators, *Radio News*, January, 1927, for direct-current battery eliminator; and *Radio Broadcast*, January, 1927, for combined eliminator and amplifier.

A tube operating directly from a 110-volt city power line, either direct or alternating current, is shown in figure 467. This has a screw base and is designed to be inserted into standard electric-lamp sockets. The heating element is formed of Nichrom resistance ribbon wound spirally on a rod of "alundum." "This serves only to heat the cathode element, which provides the necessary emission of electrons. A thin quartz tube is fastened to the base and extends up into the tube. This quartz tube is sealed at the upper end to permit the insertion of the heating element." The latter is renewable.

Late in the spring of 1926 the production of a "three-in-one" tube was announced. This was invented by Dr. Siegmund Loewe, of Berlin, Germany. Within a single evacuated glass bulb are contained detector elements, two sets of amplifying elements, two glass-enclosed resistances, together with condensers for resistance-coupled amplification, and connecting leads to the external circuit. The tube is 6 inches high and 1¾ inches in diameter. It is designed for operating with a 4-volt filament supply. There are six prongs at the base, hence special sockets are required. It is claimed that this tube greatly reduces distortion, static, etc.

386. In the Walter Reed Hospital in Washington, D. C., 1,800 head phones and five loud speakers are operated from a "radio central." which provides entertainment to the veterans of the World War in this manner, using a single Fried-Eisemann five-tube neutrodyne receiver for the purpose of bringing in the radio vibrations in the first place. The general lay-out of this installation is indicated in figure 469. It was designed by Sergeant T. F. Prendergast. Only the radio-frequency amplifier and detector tube of the netrodyne set are used, on account of audio-frequency amplification being otherwise obtained. The detector output of this receiver goes into a Western Electric impedence balancing transformer, type C109, then into a 50-watt push-pull amplifier. This is a Western Electric amplifier, type 13B, from their number 3 lecture outfit. It employs four 5-watt Western Electric tubes, type 105B, drawing 1 ampere each, with 12 volts on the filaments and 240 volts on the plates. Storage batteries are used for both filament and plate supply.

From the push-pull amplifier, the voice-frequency current

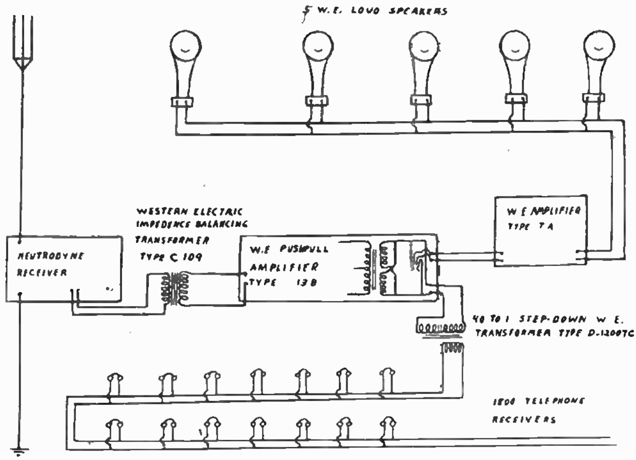


Fig. 469. Diagram Showing Arrangement of Apparatus at Walter Reed Hospital, Washington, D. C.

passes through a 40 to 1 step-down transformer, Western Electric type D-12007C, and from the secondary of this transformer regular stranded telephone cable is run all around the grounds from building to building, and ward to ward, 1800 Brandes 2200-ohm head telephones being connected across this line in parallel.

A second outlet from the 13B amplifier leads to a Western Electric power amplifier, type TA, a diagram of which is shown in figure 411. Five large Western electric loud speakers, arranged in the main halls, are connected across this line in parallel.

The volume of the signals in the 1,800 head phones is fully as great as that when only one is connected to the outlet of the average five-tube receiver, and the patients are thus provided with whatever is "on the air" only one operator being required. Duplicates of this system have recently been installed in several apartment houses, and this may be the solution of the apartment house radio problem.

A telephone line leading from a microphone circuit located in the Red Cross Building in Washington, about five miles from the hospital, may be connected to the 13B amplifier, using this to increase the volume of the voice-frequency current for the purpose of delivering speeches, locally, to the patients in the hospital. No radio transmitting apparatus is required for this.

387. The sensitive types of vacuum-tube receiving sets have made the loop antenna popular. Besides being convenient and sightly, the loop has the advantage of being directional. However, the volume and distance of any receiving set are increased by the use of a well-constructed outdoor antenna. At A, fig. 470, is shown a method of switching a receiver to loop or elevated antenna at will. Tap switches give selective tuning, and can be made to fit snugly if properly equipped with springs which press the switch levers against the studs. The loop is mounted in such a manner that it can be rotated. A telephone jack in the top of the receiver cabinet is convenient mechanically, but has the disadvantage of inserting the capacity of the jack into the radio-frequency circuit where such pains are usually taken to eliminate capacity. A separate support, with flexible leads is better. A ball bearing, such as is used in electric motors, makes an ideal mounting for a rotating loop.

In some cases the loop is made of thin copper "ribbon" about an inch wide. Sometimes two loops of different size are mounted on the same shaft, with the smaller one inside of the larger one. This is known as a loop-coupler. The two coils may be connected in series, on the order of a large variometer, or the outer one may be shorted, and the smaller one used as an "exploring coil," as in the goniometer. Two large coils mounted at right angles to each other, with a small third coil for exploring, is an arrangement frequently used on airplanes. If the single loop be connected in series with the antenna and primary of a receiving coupler, as in C, Fig. 470, the energy advantage of the larger antenna is gained, with the added advantage of the directional factor of the loop. At D is a combination which is non-directional, but which increases the volume of the received signals.

It has been found that a loop shaped as shown at B, Fig. 470, gives the best results. This is on account of the manner in which the vertical wires cut the electromagnetic waves of the oncoming signals. The wires are spaced about one inch apart, and the higher the vertical sides the better, that is, three or four feet gives better results than less. Wooden coat hangers have been used for supporting the wires in this position.

When a loop is rotated so that the horizontal portion of it is parallel to a line drawn between the receiving and transmitting station, the signals are loudest, and when the plane of the loop is at right angles to this line, the transmitting station is completely tuned out.

While the loop is not grounded through a wire, as is the elevated horizontal antenna, there is a capacity between the loop and the ground, and this capacity affects the wave length operation of the loop. The *loop* must be tuned by a variable condenser, as it is distinctly an *inductance type of antenna system.* The condenser is of the usual capacity for a receiving circuit secondary, and is customarily shunted across the terminals of the loop. The *elevated* antenna is in itself a *capacity system,* hence it is tuned by a variable inductance in series.

There is no such thing as a receiving set "operating without antenna." The loop is an antenna. The coils of wire composing the receiving coupler may, in rare cases, serve to pick up the energy of the signals, in which case *they* are an antenna system.

Generally speaking, the less sensitive is the receiver, the more efficient must the antenna be. Loops and indoor antennæ are not usually satisfactory with plain crystal-detector

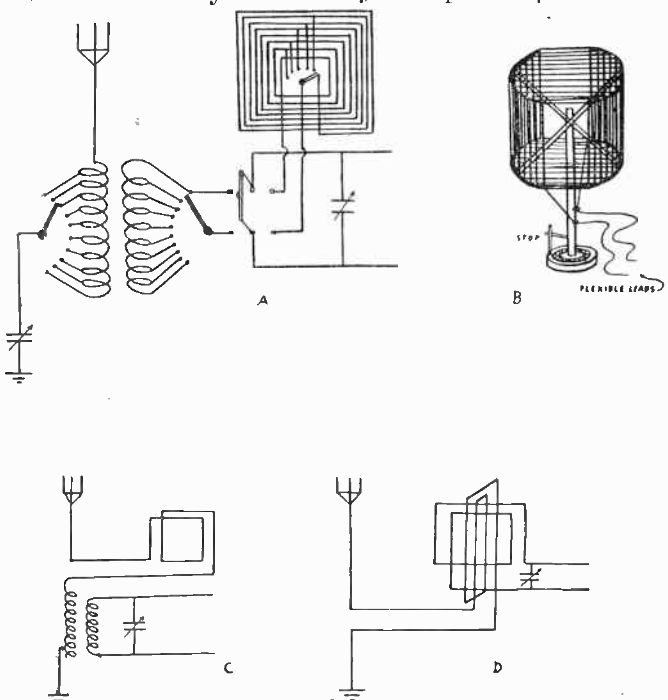


Fig. 470. Loop-Antenna Arrangements.

INDUCTANCE AND FREQUENCY RANGES OF COIL ANTENNAS. (Used with a 0.0005 µf. Variable Condenser.)

In this table we have assumed the minimum capacity of the condenser to be 0.00005 µf. (Inductance in microhenries. Frequency in kilocycles per second, and all lengths in inches.) Length of Side of Coil in Inches

(Courtesy of Bureau of Standards and Radio Leafax)

No. Turns	10: L µh.	10: Frequency Max.	10: Frequency Min.	12: L µh.	12: Frequency Max.	12: Frequency Min.	15: L µh.	15: Frequency Max.	15: Frequency Min.
Spacing of Turns=¼ Inch									
4	10	7120	2252	13	6240	1978	17	5470	1730
8	31	4030	1280	41	3510	1112	55	3035	962
12	60	3750	921	78	2546	807	106	2185	692
16	91	2910	748	131	1968	623	165	1752	556
20	124	2020	641	168	1736	550	235	1467	465
Spacing of Turns=½ Inch									
4	9	7500	2375	11	6780	2150	15	5820	1842
8	24	4580	1456	32	3980	1260	44	3380	1075
12	43	3430	1086	57	2980	943	80	2515	798
16	63	2830	898	86	2425	768	121	1858	648
20	82	2485	788	113	2120	672	162	1766	561
Spacing of Turns=¾ Inch									
4	8	7960	2520	10	7120	2252	14	6020	1907
8	20	5025	1593	27	4330	1372	38	3650	1156
12	34	3875	1223	46	3320	1052	66	2770	878
16	47	3280	1040	66	2770	878	96	2295	728
20	61	2875	913	84	2450	777	28	1990	630
Spacing of Turns= 1 Inch									
4	7	8510	2695	9	7500	2375	12	6500	2060
8	17	5460	1726	24	4580	1456	33	3915	1242
12	28	4260	1346	39	3605	1142	54	3060	971
16	38	3650	1156	53	3090	980	79	2530	803
20	47	3285	1040	66	2770	878	101	2240	709

No. Turns	18: L µh.	18: Frequency Max.	18: Frequency Min.	20: L µh.	20: Frequency Max.	20: Frequency Min.	24: L µh.	24: Frequency Max.	24: Frequency Min.
Spacing of Turns=¼ Inch									
4	22	4700	1520	25	4500	1426	32	3980	1260
8	71	2670	845	81	2504	792	103	2215	703
12	137	1912	608	158	1790	567	203	1576	500
16	215	1535	487	251	1422	452	323	1252	397
20	306	1287	407	357	1192	378	462	1047	332
Spacing of Turns=½ Inch									
4	19	5170	1635	22	4800	1522	28	4260	1347
8	57	3980	943	66	2770	878	85	2440	773
12	105	2195	696	123	2030	643	161	1773	562
16	160	1780	563	188	1642	521	245	1437	456
20	219	1518	482	259	1396	443	342	1218	386
Spacing of Turns=¾ Inch									
4	17	5470	1730	20	5030	1592	25	4510	1427
8	49	3210	1017	57	2980	945	74	2610	828
12	87	2410	763	103	2215	703	135	1938	613
16	29	1932	628	153	1820	577	204	1573	498
20	68	1735	550	205	1572	498	276	1355	329
Spacing of Turns= 1 Inch									
4	16	5630	1783	19	5170	1635	24	4600	1456
8	44	3390	1075	51	3150	998	67	2750	870
12	75	2600	823	90	2370	752	119	2060	653
16	108	2165	687	129	1982	627	174	1705	542
20	140	1902	602	170	1727	547	232	1480	468

No. Turns	28: L µh.	28: Frequency Max.	28: Frequency Min.	32: L µh.	32: Frequency Max.	32: Frequency Min.	36: L µh.	36: Frequency Max.	36: Frequency Min.
Spacing of Turns=¼ Inch									
4	39	3605	1142	45	3355	1063	52	3120	988
8	126	2005	636	151	1832	580	173	1710	542
12	248	1425	452	291	1320	418	346	1210	383
16	399	1124	357	478	1028	326	559	952	301
20	574	398	297	688	858	271	809	792	250
Spacing of Turns=½ Inch									
4	34	3855	1222	40	3555	1126	46	3315	1050
8	104	2206	685	127	2000	633	145	1866	592
12	198	1596	507	239	1453	450	281	1343	426
16	308	1282	407	374	1162	369	439	1072	340
20	432	1082	343	526	983	311	625	901	285
Spacing of Turns=¾ Inch									
4	31	4030	1278	36	3750	1186	43	3430	1086
8	92	2345	743	112	2126	673	129	1982	628
12	169	1732	548	204	1573	498	243	1442	457
16	258	1400	443	315	1267	402	374	1163	368
20	354	1194	379	434	1080	342	522	986	312
Spacing of Turns= 1 Inch									
4	29	4175	1324	35	3805	1204	40	3555	1126
8	83	2470	782	102	2230	706	118	2070	657
12	150	1836	582	182	1670	528	217	1530	484
16	222	1512	478	269	1372	433	328	1242	393
20	300	1298	412	372	1167	370	441	1072	340

receiving sets, because these sets lack the amplifying characteristics for building up the minute energy received in this manner. Many homes where vacuum-tube receivers are installed are equipped with regular antennæ, arranged in the attic, or under the ceilings of the rooms. While not as satisfactory as a higher outdoor antenna, these often suffice, and are generally found to bring in greater distances than the loop. It is necessary to insulate the indoor antenna as carefully as the one outside, and all connections should be soldered to reduce loss.

The accompanying table shows the frequencies, in kilocycles, and inductances, in microhenries, of loop antennæ, or coils, constructed of No. 14 wire. A change of a size or two in the wire makes little appreciable difference. If a .001 condenser is used instead of the .0005 given in this table, multiply the values given in the table by .707:

388. Among the many *"troubles"* encountered by users of radio receivers, picking up a *hum* from alternating-current power lines, or nearby generators, is one of the most common. Antenna wires should always be placed as far as possible from power lines, and never parallel to them. If placed at right angles to lines in the vicinity, and still the hum persists, transposing the antenna wires, as shown at A, Fig. 471, has been found effective in overcoming the trouble.

If it is difficult to obtain a good ground, a counterpoise, as shown at B, Fig. 471, may be substituted with good results.

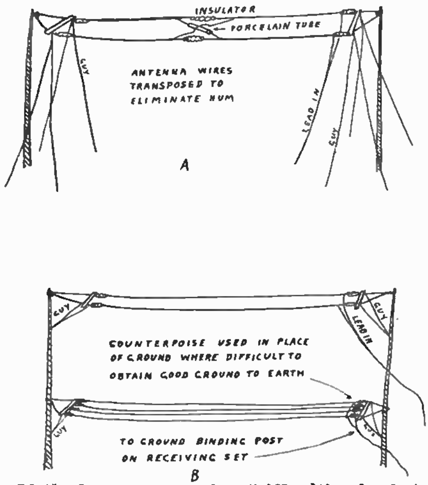


Fig. 471. Two Methods of Overcoming Difficulties in Antenna Systems.

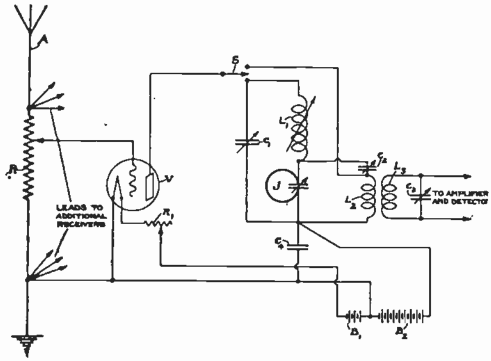


Fig. 472. Taylor Multiple-Reception System. (Patent 1,489,287, April, 1924.)

In apartment houses where the use of many antennæ on the roof is prohibited, it is desirable to operate several receiving sets on a single antenna. This problem has not been completely solved, as yet. However, a system of multiple reception worked out in the U. S. Navy by Albert H. Taylor, has been patented, and it is predicted that it will find wide application, perhaps with improvements, in the future. In figure 472, A represents the community receiving antenna, R a high resistance in series with the same, V a vacuum tube, L_1 and C_1 a tunable high-frequency circuit, and J a "rejector." The latter consists of a single turn of heavy copper ribbon, shunted by a large capacity condenser, having low resistance, and used for tuning the rejector element to the desired wave length. L_2 and C_2 are tuning elements, to which is inductively coupled the detector circuit of the usual receiving set. Each receiver connected to the antenna must be equipped with a similar selecting and rejecting system. The switch S is for the purpose of throwing the selecting system temporarily out of the system for the purpose of picking up the signals. After they have been obtained, this switch is thrown in the down position, and the intermediate circuits are tuned until the desired signal is heard in the receiving set, and the undesired signals are excluded.

A rather crude, but comparatively successful, method of using one antenna for a number of receiving sets is to merely wind several turns of wire brought from the antenna binding post of each receiver around the common lead-in. The receivers are grounded as usual.

389. The *"trouble shooter"* is likely to run across one or

more conditions which are frequently found in the average receiving set. Occasionally a new and rare difficulty may appear, calling for the exercise of ingenuity. Among the common troubles encountered by owners of radio receivers are interference, static, radiation, locally produced noises, distortion, blowing of tubes, failure of an apparently well constructed receiver to operate and variation of signal strength when no tuning is being done.

Interference is not always easily overcome. It is not a new problem, but its importance has become more sharply realized since the sudden increase in the number of receiving and transmitting stations. Broadcasting stations are now allotted staggered wave lengths, operate in some cases on alternate nights, etc., so that overlapping of broadcast wave lengths is less troublesome than formerly. During broadcast hours operators of ship stations have been instructed to do all within their power to avoid causing unnecessary interference, by working on the minimum power with which their business can be transacted, and on wave lengths longer than those which the broadcast listeners are likely to pick up. But interference still remains a problem calling for solution. Aside from the interference caused by hearing two or more transmitting stations at the same time, there is some trouble caused by the harmonics of the long-wave high-powered commercial telegraph stations coming in on the shorter-wave-length broadcast receiving sets. It is unjust to expect these stations to cease operation in order that others may be entertained. Many of them have installed special auxiliary circuits, experimentally, in an effort to prevent this type of interference. To eliminate both kinds of interference, at the receiving station, inductively coupled "wave traps" have been constructed, both as separate apparatus and as a permanent part of certain types of receivers. The latter are often called "four-circuit receivers." The wave trap may be used to absorb the signal of an undesired frequency. Incidentally it will probably absorb some of the desired energy also, and requires rather more than the skill of the average broadcast listener for successful operation.*

In figure 473, at A, is shown the simple wave trap inductively coupled to the antenna system. At B is a wave selector devised in the U. S. Signal Corps. This consists of two wave traps having different inductance, connected in parallel with each other. The resonance coil consists of a

*See *Circular Letter of Bureau of Standards, No. 182,* on *Electrical Interference with Radio Operation.* Also, *Radio Interference, Serial Report of the National Electric Light Association,* 29 W. 39th Street, New York.

single layer of No. 28 cotton-covered copper wire wound over an eighteen-inch length of tubing four and one-half inches in diameter. One end of this coil is left open, the open end having a higher potential than the end attached to the circuit by a wire. Around this coil are placed two slit brass rings, arranged mechanically so that they can be moved upward or downward over the coil, without actually touching it. This requires patience in tuning, but proves efficient for the purpose for which it has been designed, that of selecting signals from one station at a time, to the exclusion of others.

A well constructed receiving set, with provision for fine adjustments, should tune selectively. If it does not the condensers may be at fault. They may have a high resistance in the material composing the plates and leads, or there may

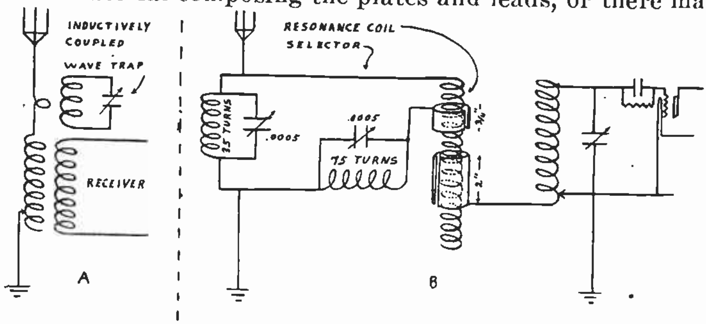


Fig. 473. Wave-Trap Methods of Selective Tuning.

be a poor contact at some slipping contact point. The latter is most easily overcome by using flexible "pig-tail" connections. There may be leakage at the edge of the plates, due to too close proximity to wires or other parts of the apparatus. These losses may cause broad tuning by decreasing the general efficiency of the condenser and making the resonant point of tuning vague.

390. The elimination of *static* from the receiving telephones is more difficult than is the tuning out of interference. It has been often stated that "no receiver is good beyond the static level." That is, increasing its sensitivity has practical limitations. If a set in Chicago is capable of bringing in a broadcast program from Mexico, it is also capable of rounding up all the static in the United States and Canada and bringing that in also. This is the logical result of such extreme sensitiveness. Strictly speaking, it is not the "static," but its *dynamic discharge,* which sets up the disturbing waves that are heard in the telephones. "Static

eliminators" are heralded from time to time, but seldom heard of again. So far, the most successful method of cutting out the static is to cut out the distant signals also. In some cases running the lead-in through a grounded lead pipe may reduce the noise in the receivers.

Among the many devices which have been attempted in the way of static "eliminators," the one worked out by Dr. Galen McCaa has become best known. It has had many variations, the latest one being shown in figure 474. This is not so successful with regenerative receivers, and might more properly be called a static *reducer* than an eliminator. Briefly, the theory is as follows: When tuning a receiving set for a certain wave length, the apparatus is set for some particular frequency. Now it happens that it is possible to force this apparatus to vibrate at this same frequency by a mechanical shock. This is one way in which static affects a receiver. It *shocks* it by a severe electrical jolt. The trick is to let the signal through at the same time that the apparatus is being protected from the shock of the static. This is accomplished by use of inductances having "bucking" magnetic fields, and a signal frequency synchronous driver.

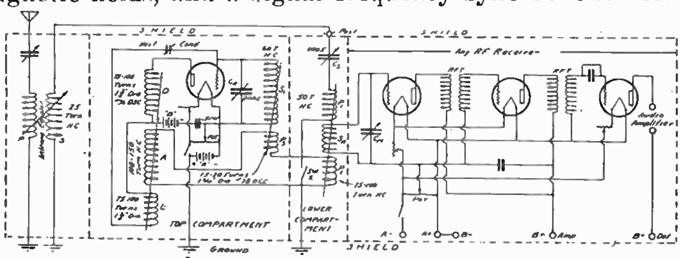


Fig. 474. McCaa Static Eliminator Consisting of Static-Balance Circuit and Signal-Frequency Synchronous Driver.
(Radio, March, 1926.)

The antenna circuit is tuned to the frequency of the desired signal. The incoming signal is transferred to a 25-turn honey-comb coil, S. With switch X closed, variable condenser C_s is adjusted for resonance. Then coil S_m is tuned by condenser C_m of the receiver, and the signal is heard. Switch X is opened, which brings P_2 into bucking action on P_1, with the result that both static and signal are eliminated from the receiver. However, some current flows in coil P_3, which is conveyed to S_1 C_r, and to the tube. The signal frequency appears at D, which is in such a relation to A as to neutralize the magnetic lines of force of A. A then acts as a short-circuit across P_2, and the signal is passed into the main receiver. It has been learned that the static oscillation is similar to a damped-wave train, corresponding to the natural oscillation period of the secondary of the receiver, and having a decrement in proportion to the resistance of this circuit. Small capacity and large inductance decreases this decrement.*

Many times what is believed to be static actually originates in the receiving set, and may come from badly soldered joints, batteries in poor condition, a bad tube, or a bad or the wrong grid leak. To test for locally generated "static" the antenna and ground terminals of the receiver may be shorted by a piece of wire disconnecting the antenna and ground, and the tubes lighted. If frying, spitting, or crackling noises are heard in the telephones, nature is not to blame.

Two small voltmeters designed for battery use, should always be kept near the receiving set, and used, one for testing the filament cells and the other for the higher voltage plate battery. In testing, these instruments should merely touch the opposite terminals for deflection of the needle, and should not be held there long enough to still further discharge the battery. Sometimes batteries which are not run down will cause sputtering noises. A fixed condenser of about .001 mfd. capacity shunted across the plate battery connections will usually overcome this. A .01-mfd. condenser is also good across the filament battery terminals.

Receiving sets in which stranded wire connectors are used, may be poorly soldered. Or where bus-bar wire is used, it may have worked loose and caused a poor connection. Sometimes a broken strand in the telephone cords will make an excellent imitation of static, especially when it is moved. Corrosion at the joints, on the tube contacts, etc., will cause scratching noises to be heard. Some receivers which were soldered with ordinary muriatic acid soldering paste soon exhibit this symptom. When the corrosion has eaten its way into the metals the only remedy is to discard them. Loose binding posts may also cause noises, and poor contacts on rheostats.

A bad tube in the circuit will cause "frying" noises. Some tubes may light, without being in good condition for functioning in a radio circuit. Removing a suspected tube and experimenting with another one, will prove whether or not a tube is producing noises. A continuous shriek in the tele-

*For constructional details for building a McCaa static eliminator, see *Radio*, March, 1926.

phones, one which can not be tuned out by any adjustment, is likely to be caused by a tube which is "giving up its dying gasp," or by an A battery which should be renewed or recharged. This can happen even when the battery gives a reading of the required voltage when short-circuited by a voltmeter.

Noises may be caused by the antenna joints being corroded, or loose and moving and scratching in the wind. The antenna is exposed to the weather, and should be examined frequently for signs of corrosion.

If a receiving set is placed near a lighting fixture operated on alternating current, the purr of the power line will no doubt be heard in the telephones. The remedy is obvious. The receiver should be moved to another spot. Dust in the set, especially on condenser plates, will make unpleasant noises in the telephones. A receiving set should be carefully dusted with a long-handled paint brush. The condenser plates may be cleaned by using a fuzz-covered wire, such as is sold for cleaning smokers' pipes. In doing this it is necessary to be careful not to bend the plates of the condenser.

A grid leak of the wrong value will cause noises much like static, and at other times takes the form of a staccato beat. If a variable grid leak is used, it is easy to vary its resistance. Otherwise it may be necessary to experiment with several leaks of different value until the correct one is found. A sound like beating a drum is sometimes caused by an open circuit.

391. If a receiving set tunes in a clear shrill *whistle* which varies in pitch as the tuning is changed, it is probable that a neighboring regenerative receiver is radiating vibrations which are being picked up by the antenna. If a neighbor tunes in the same kind of a whistle it may be that the interference is being caused by *your* regenerative receiver. The remedy is to *avoid radiating receiving sets*. If adding one or two stages of radio-frequency amplification between the detector and antenna of a regenerative receiver is not feasible, the operator can at least learn to prevent its squealing. He can determine what adjustments cause these sounds to be heard in his own telephones, and avoid using those adjustments.

Another type of whistle, heard in all the receivers in a certain locality as a high clear tone of practically constant pitch is caused by the *heterodyning of two sets of radio-frequency waves from two transmitting stations* which may be many miles apart. This seldom occurs when the transmitting stations are properly tuned to their allotted wave lengths, but happens occasionally as an accident. Crystal control of the transmitter appears to be the remedy for this.

The radiating receiver and the heterodyne beat note produced by the collision between the waves of two transmitters each produce continuous vibrations of equal amplitude. A regenerative receiver may also cause another type of interference due to its *reradiating* of modulated signals which it has picked up, in a more or less distorted condition. The conductively coupled regenerative receiver, which generates oscillations directly in its own antenna system, is most likely to cause this disturbance.

Squeals and howls are often present in a receiver when the hand of the operator approaches the tuning dials. This is known as *"body capacity,"* and is not likely to occur when the cores of the audio-frequency transformers are grounded, or when a grounded metal shield is mounted on the inner side of the panel. Sometimes, when tuning a receiver which does not otherwise create squeals, it is sufficient preventive for the operator to touch a finger of the left hand on the metal part of the ground binding post, while the dials are turned with the right hand. This grounds the body which causes the "body capacity."

392. *Antennæ in close proximity* often interfere with each other. There may be *coupling between them,* so that tuning a receiver connected to one affects the tuning of the receiver connected to the other. A small antenna on the same roof with a larger one will be overpowered by the larger antenna. When the receiver connected to the larger one is tuned to a certain wave length this is likely to make the signals on this particular wave length suddenly much louder in the receiver attached to the smaller antenna, which makes it necessary for the owner of the smaller antenna to listen only to the stations which the owner of the larger one chooses to tune in, as it will be difficult for him to tune these stations out.

There is also a weakening of the signals for all receiving stations in a location which is crowded with antennæ and receiving sets. Each antenna absorbs a portion of the energy of the radiated waves, which decreases their energy just that much. A solution of this phase of the radio-broadcasting problem has not yet been reached. Some predict that eventually the elevated antenna will completely disappear from the house tops. This will mean more sensitive receiving sets, and loop antennæ, or possibly some underground substitute.

398. *Distortion* is fully as troublesome as interference and static, but is more easily overcome, because it is caused by conditions under the control of the operator. Distortion of sound waves is something like the way the curved and warped mirrors seen at pleasure resorts distort the image of a person standing before them. The image is there, but all bent out of shape. The person doesn't look like that, which can be proved by the substitution of a mirror having a level surface. If sound waves are bent out of shape, the apparatus through which they have passed in the detector and audio-frequency amplifier have produced a false impression. Vacuum-tube detector circuits may cause some distortion. With the different qualities and constants of vacuum tubes obtainable, this is not impossible. Often a change in plate voltage will improve the quality of the sounds coming through the apparatus. A *rheostat in series with plates and B power supply* gives excellent results. This is included in some of the newer factory-built receivers and called a "volume control." It also is a distortion reducer. A good crystal detector will no doubt give more faithful reproduction of the sounds transmitted than an improperly operated vacuum tube, but it is possible to operate the tube detector in such a manner as to avoid distortion. Using audio-frequency transformers of a different, and not too high step-up ratio, helps to prevent distortion in an amplifier. When they are of high ratio and the same ratio, any warped waves in the first stage are amplified in the second stage, while if different, this effect is neutralized.

Some head telephones cause distortion, when they are poorly constructed with poor iron cores in the magnets, or having a pronounced resonance frequency above and below which their efficiency decreases rapidly. But this is rare with the standard makes of telephones. Loud speakers, quite generally, do cause a great deal of distortion of the audio-frequency vibrations, and should be selected with care. The distortion may be caused by the internal mechanism, or solely by the horn, which may be of the wrong material or shape for giving accurate reproduction. A simple way to determine this is to remove the loud speaker and listen for a while with the head telephones. If the signals are not distorted in the telephones, it is obvious that the receiving set and telephones are performing properly. If distortion is present in the telephones, it is well, if possible, to experiment with more than one pair of phones to make sure that they are not to blame. If the trouble appears to be in the receiving set, and the detector circuit has been proved satisfactory, the audio-frequency transformers are no doubt the cause. Badly designed and improperly connected audio-frequency transformers probably cause more distortion than any other single thing about a receiving set.

The direction of the windings in the telephones is such that with the plate battery current passing through them in one direction they have a tendency to add to the magnetism of the permanent magnets, and if in the other direction to decrease this permanent magnetism. It can be seen that if they are connected so as to take advantage of the increase and avoid the decrease, the life of the telephones will be lengthened considerably. Some manufacturers are now marking the telephones for this purpose. The end of the telephone cord which should be connected to the positive terminal of the plate battery is encased in red cotton tubing, or otherwise marked in red.

The waves are passed inductively from the primary to the secondary of an audio-frequency transformer, there being no conductive connection between these two circuits. Poor iron cores, causing absorption or eddy currents, may cause distortion of the signals. In connection with the question of resonance, the impedence of the transformers is greater on certain frequencies than others, hence some sound frequencies may be amplified more than others. The composition and preparation of the core effects the impedence, hence this is an important consideration in the designing of transformers which it is desired to have operate equally well on all audible frequencies.

For radiotelegraphy, audio-frequency transformers have been designed to have a low impedence around 1,000 vibrations per second, which is the frequency of the note most employed in this kind of communication. With broadcast reception the question is more complicated, on account of the variations of frequencies due to different pitches and the overtones of varying qualities. The wonder is that these frequencies can be held, with the slight amount of distortion obtained under favorable conditions, throughout the different stages of amplification. The use of heavier wire than in the early types of transformers, as well as careful selection of core material, has proved successful in reducing impedence.

The manner of connecting the transformers in the circuit is also of importance. This depends upon the manner in which the coils composing the transformers are wound. Usually they should be connected as shown in figure 415, that is, the two "inside" terminals of the transformer are connected respectively to the plate battery positive, and the negative of the filament battery, while the two "outside" terminals are connected respectively to the plate and grid of successive tubes. Markings on transformers are not standardized, and in constructing a receiving set it is sometimes necessary to experiment with these connections until the best results are obtained. Wrong transformer connections will produce weak signals, and in some cases great distortion.

The amplifier tubes must be operated at the best point on their dynamic curve. That is, if a curve, showing the dynamic characteristic of an amplifier tube be made, plotting grid voltage against plate current, at a fixed plate voltage, the "curve" must be a straight line. There must be no sudden increase in plate current, if distortion is to be avoided. A "C" battery in series with the grid assists in maintaining this condition. Also, the filament rheostat must be adjusted to permit the tube to be lighted to a sufficient brilliancy to allow of a desirable amount of amplification, but if given too much current, distortion will result immediately.

Often a "howling" noise is heard in the audio-frequency amplifier, due to magnetic interaction between the transformers. If a wire be connected from the frame of the first transformer to the ground binding post, the howl will probably disappear. Connecting a .001-mfd. fixed condenser in shunt to the primary of the first audio-frequency transformer is recommended.

If it is desired to fill a large hall with the output of a loud speaker, increasing the amplification will not give as satisfactory results as adding two or three loud speakers in parallel. This draws more current, due to the resistance of the loud speaker coils being in parallel, and each operates individually, thus giving increased total volume and avoiding the distortion which is inevitable if a single unit is overloaded.

394. If, upon turning on the filament battery of a receiving set, one or more *tubes are burned out,* either the batteries are connected incorrectly or there is a short-circuit in the receiver. As this is an expensive way to gain experience, caution is recommended. It is well to test the filament circuit with a small six-volt flash-light lamp, which may be easily mounted inside the base of a blown-out vacuum tube;

and battery connections should be carefully inspected after every removal and reconnection. The most common cause for burnt-out tubes is putting the plate battery voltage on the filaments. And of course the polarity of the batteries must be as specified in the receiving circuit. The filaments will light if the A battery is reversed, but if the polarity of the B battery is reversed, nothing will be heard, and in some circuits this may do a great deal of damage.

A filament switch should be used in series with the A battery. These come in various types of push-button styles for mounting on the panel of the receiver, and are a great convenience as well as a protection. No disconnecting of the wires at the binding posts is then necessary. The filament switch besides saving the tubes and batteries, permits a temporary interruption, when receiving, without loss of the station.

Sometimes a tube is ruined through use of the wrong rheostat. When two tubes are connected in parallel on the same rheostat, the resistance is decreased to permit the flow of the double amount of current. Standard tubes are usually accompanied by printed information stating the filament and plate voltage for which they are intended, also the current normally drawn by the filament. Determining the proper resistance to use for controlling the filament current is a simple application of Ohm's law. Referring to the table of Radiotron Characteristics on page 342, it will be seen that the UV-199, for instance, is rated as drawing .06 ampere on 3 volts. Hence, applying the rule, resistance is equal to voltage divided by current, the resistance of the filament is found to be 50 ohms. This would be the condition existing if the voltage of the batteries were exactly 3 volts, and the rheostat adjusted to zero resistance. By using an additional, and variable resistance, in the form of a rheostat, in series with the resistance of the filament, we can use a battery having more cells and a somewhat higher voltage, gradually reducing the resistance of the rheostat as the voltage of the battery decreases from deterioration, until it has dropped to less than 3 volts, at which point it is necessary to renew the battery in order to maintain the required amount of current to light the filament. A 4½-volt battery, of three dry cells, is actually what is used with the UV-199 tube. When it is new and has a voltage of 4½, a sufficient amount of resistance must be inserted to cause a volt drop, or "line drop" through the rheostat so that the voltage at the terminals of the filament is 3 volts. This is found by calculating the resistance necessary to permit 4½ volts to provide .06 ampere, and subtracting from this the known resistance of the filament. This proves to be 75 ohms minus 50 ohms, signifying that a 25 ohm rheostat is required. This rule applies to all other types of tubes, of course. Also, where tubes are used in parallel with a single rheostat, the parallel resistance of the filaments must be included in the problem.

Marking the battery leads in some manner is an excellent precaution. The easiest way to do this is to use wires having different colored insulation, always employing the red for the positive B terminal.

Binding posts to which battery leads are attached are always marked, but with some types of binding posts, it is possible to remove the tops and replace them incorrectly. The battery polarities should be marked, in addition, on the panel or bakelite strip to which they are attached.

A tube which has been burned out, may sometimes be restored to life, provided that no gap has developed between the ends of the filament wire. Frequently the filament wire only cracks, and in this case the tube may probably be rejuvenated. The same treatment applies also to tubes which will still light, but which are "dead" to signals. This "miracle" is accomplished by lighting the filaments for ½ minute on 16 or 18 volts, and afterwards for ten minutes on 10 volts. This will work on storage batteries, but we have found alternating current, stepped down through a toy transformer, to give the best results. The theory of rejuvenating the "dead" tube, is that the alternating current causes a change in position of some of the electrons in the filament, and gives practically a new outside surface, so far as available electrons for accomplishing work is concerned. In the case of the cracked filament, the arc usually welds the wire. For dry-cell tubes the first voltage should be 12 volts and the second one 8 volts. An inefficient tube can often be made to perform better by simply burning it for about ten minutes at full brilliancy on the 6-volt storage A battery with the B battery disconnected.

395. If upon sitting down to listen, on what appears to be a correctly wired receiving set, *nothing is heard,* aside from the possibility of an error in the circuit, this may be caused by something very simple. The trick is to find the simple cause. Perhaps the most common cause of this is a short-

circuited fixed condenser, either shunted across the telephone connections or the first amplifying transformer. This may be caused by the use of a hot soldering iron on a condenser composed of thin copper or tinfoil and waxed paper, which is not intended to withstand the heat. Where fixed condensers are soldered into a circuit, this must be done very cautiously. Probably the next most common cause for silence in a receiving set is a poor contact between the prongs on the base of the tubes and the springs in the sockets. The springs should press tightly against the prongs. They may be carefully raised with the finger, or a screw driver, of course disconnecting all batteries first. (A long handled button hook is convenient for this.) Tube sockets made of materials which melt when the soldering iron is near them are worthless. Some of these sockets soften, during the construction of a receiver, and harden again, leaving the springs at a lower position than formerly.

It is a good idea to prevent trouble from loose socket prongs by tightening them and soldering the under side of the prongs to the screws before installing the socket.

Where tube adapters are used, for inserting dry-cell tubes into standard tube sockets, there is likely to be a loss of energy or a poor contact. For this reason many of the more recent dry-cell tubes are manufactured on a standard-size base, so that the tubes are interchangeable without an adapter.

Sometimes everything is all right, except the contact between a jack and a telephone plug. The jack springs may be loose, or the plug may go in too far or not far enough, to make contact to each side of the circuit.

The plug itself, with its contacts for the phone tips, sometimes develops a short or an open-circuit, which may prove quite mystifying until located.

If there is reason to suspect the coils in a receiving set, they may be tested with a flash-light lamp in a small socket, in series with a dry cell. They may be connected in series with the telephones also if desired. If the lamp fails to light when the ends of the coil are connected in series with the lamp and battery, there is probably an open in the coil.

Sometimes the plates of the variable condenser touch, which causes a short-circuit. If the lamp lights when the fixed and rotary plates of the condenser are placed in series with it and the battery, the condenser is short-circuited. Usually the plates may be straightened, but this requires care and patience. A good voltmeter in series with a 22½ volt B battery may be used instead of the lamp, if available.

A receiving set which has a painted cabinet, or baseboard, or any paint with a mineral base about it in any way, is not likely to give satisfactory results. The paint is more or less of a conductor, and may in some cases cause an actual short-circuit. In one case a student made up a superheterodyne receiver which looked beautiful but failed to function properly, and the trouble was finally traced to some heavy *lead pencil marks* which he had left all over the inside surface of the panel, after having marked out his plan in this manner. The graphite is sufficiently conductive to form a practical grid leak when placed in series with the grid of a vacuum tube.

Wooden base boards may cause trouble if not perfectly dry, by absorbing moisture, hence the increased popularity for the use of bakelite, hard rubber, or similiar substances for a mounting for tube sockets, transformers, etc., inside of the cabinet. This can be attached to the front panel by small angles made of sheet brass.

396. The effect of *signals swinging in and out,* when the operator is not tuning, may be caused by loose connections in the receiver or antenna, or by the antenna being improperly guyed, and allowed to swing in the wind, possibly touching a tree or other conductor to earth. It may be due to things beyond the control of the operator, such as the *fading* which is believed to be caused by the action of the ionized air at the upper strata of the atmosphere.

Variations in the quality of the medium through which the electromagnetic waves travel will affect the signal intensity at the receiving station. It seems probable that the phases of the moon affect the radio reception from a distance, best reception taking place at the full of the moon. Its position in the heavens during any particular evening, or hour, may have some effect on reception from a particular locality. The position of the sun has something to do with transmission. The least energy is transmitted from any particular station when it is the hour of sunset at that station. It is also surmised that the other planets have some effect upon our radio transmission and reception, and something to do with what we call static. This appeared evident at the time that Mars was close to the earth in August, 1924, at which time more than ordinary difficulty was experienced in the handling of radio communication. Also, on the morning of January 24, 1925, during the total eclipse of the sun, many freak reception conditions were recorded, the study of which will no doubt lead to increased knowledge of the performance of electric waves. While the sun was darkened, the distance range of transmitting stations was greatly increased, but there also seemed to be some change in the *direction* of propagation.

Rising or falling temperature is always accompanied by *static disturbances,* which cause trouble in radio reception. Opinions regarding the effects of cold and hot weather have passed through several changes. For some time it was doubted that temperature, if not changing, had any effect upon the transmission of electric waves. However, recently announced results of extensive experiments at the Bureau of Standards seem to prove that there was some foundation for the early notion that signals carry farthest in low temperature. High temperature appears to decrease the transmitting range and to increase the difficulty with static, so that receiving conditions are generally better in the winter than in the summer.

Certain localities are noted for giving excellent reception and others for poor reception. This may account for the so-called "long-distance crystal sets" which behave surprisingly in one place, but only ordinarily elsewhere. In cities, steel structures of various types, bridges, railways, etc., may cause absorption. They may, if standing between the receiving station and some particular transmitting station, act as a magnetic shield between the two stations, making it practically impossible for the receiver to bring in that transmitting station, although it may get others very well. In some cases the harmonics of a high-powered transmitting station situated between two points may have somewhat the same effect, as in the case of NOF, of the U. S. Navy, Washington D. C., which practically "blankets" broadcast programs between Baltimore and Washington.

The recitation of the possible troubles which may be encountered does not signify that all owners of radio receivers should expect to have trouble with them, but that in case any one of the troubles should arise, they should be able to cope with the situation.

Local programs are always available, if the receiver is in operating condition. *Reception over great distances is never certain* on account of the many natural causes which may produce variations in this reception. If it were absolutely sure under all conditions, it might not be so *alluring,* and we would be satisfied with our local programs, which are generally just as good as those from a distance.

PART FOUR

THE PRACTICAL RADIO OPERATOR

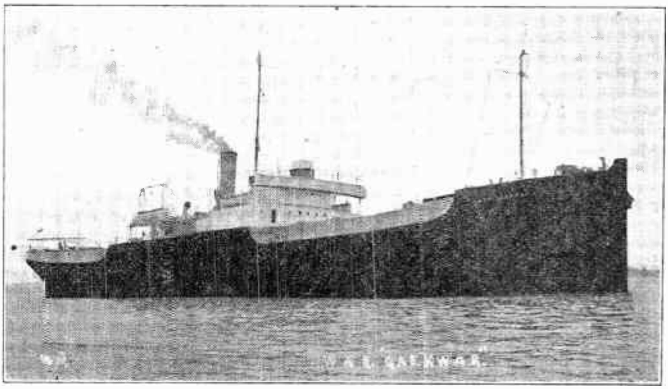


Fig. 475. S. S. Gaekwar.

CHAPTER 37

Construction and Operation of Various Types of Apparatus Used in Marine Communication

Diagrams of Complete Ship Radio Installations for Government Examination for First Class Radio Operator's License—RCA Spark and Tube Marine Transmitters and Receivers — Navy Standard Transmitter and Receiver—Independent Wireless Marine Arc Transmitter—Federal Telegraph Company Marine Arc and Spark Installation—RCA Vacuum-Tube Marine Installation—Leach Break-in Relay—Impact Transmitter—Magnetic Saturation Starter—Mercury-Valve Transmitter—Telefunken Marine Apparatus—Telefunken Installation on Dirigible Los Angeles—Apparatus Used on Vessels of the U. S. Coast Guard—Anchor Spark Gap—Stand-by Receiver—Intermediate-Circuit Receiver—Barrage Receiver—Weagent Receiving System—Tikker and Detuning CW Reception—Submarine Antenna and Underground Communication—Automatic Transmitting and Receiving—Radio Control of Moving Bodies.

397. The practical radio operator who goes to sea finds various makes and types of apparatus on board the vessels, and he is expected to be able to operate any of these. The fundamental plan of the spark type of transmitter is always the same, so if this is thoroughly understood, in one make, the others may be easily traced out. Probably after the ships are all equipped with continuous-wave transmitters, the old spark sets will be retained and kept in working condition to be used in case of emergency. Prominent among manufacturers of marine radio apparatus is the Radio Corporation of America (Consolidated American Marconi Co., General Electric Co., Western Electric Co., Westinghouse Co., and others). One of the best known spark transmitters is the RCA 2-K. W. 500-cycle apparatus shown in figure 477. Figure 476 is a diagram of this transmitter, with storage-battery auxiliary source of power and a standard type of three-tube regenerative receiver, which is now supplied on vessels for this installation.

398. Taking this diagram up in detail, we find a *polarity-reversing switch,* connecting the complete installation to the generator line. This is used to avoid the trouble of rearranging all of the connections to the storage batteries and motor generator, in case the polarity of the line is reversed.

Exide cells, type MV-11, are generally used in this installation. The batteries are connected for charging in parallel and discharging in series, as the fully charged voltage of them is greater than that of the charging line, and it would

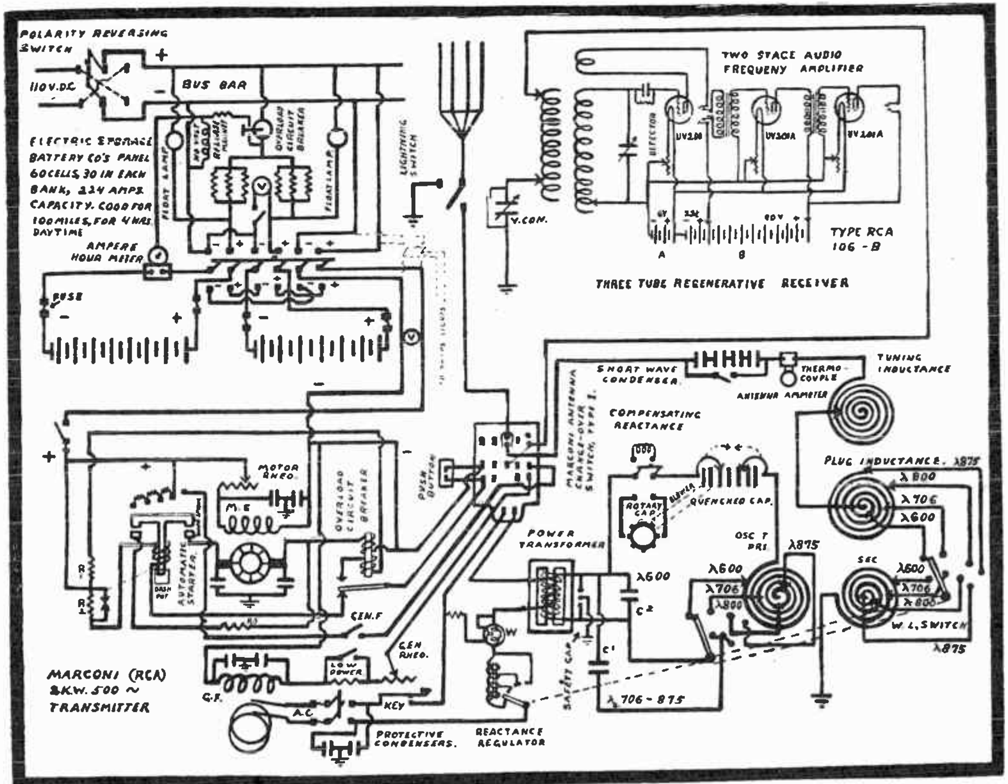


Fig. 476. Complete Wiring Diagram of RCA 2-K. W. 500-Cycle Spark Transmitter, With Storage-Battery Auxiliary and Three-Tube Regenerative Receiver.
(Prepared especially for persons applying for first-class commercial radio operator's license.)

otherwise be impossible to charge them properly. Two groups of resistance coils are connected so that one is in series with each bank of cells while on charge. An overload and underload *circuit-breaker,* which can be seen at the top of the panel in figure 478, is connected for protecting the batteries. A Sangamo mercury *ampere-hour meter* is *in series*

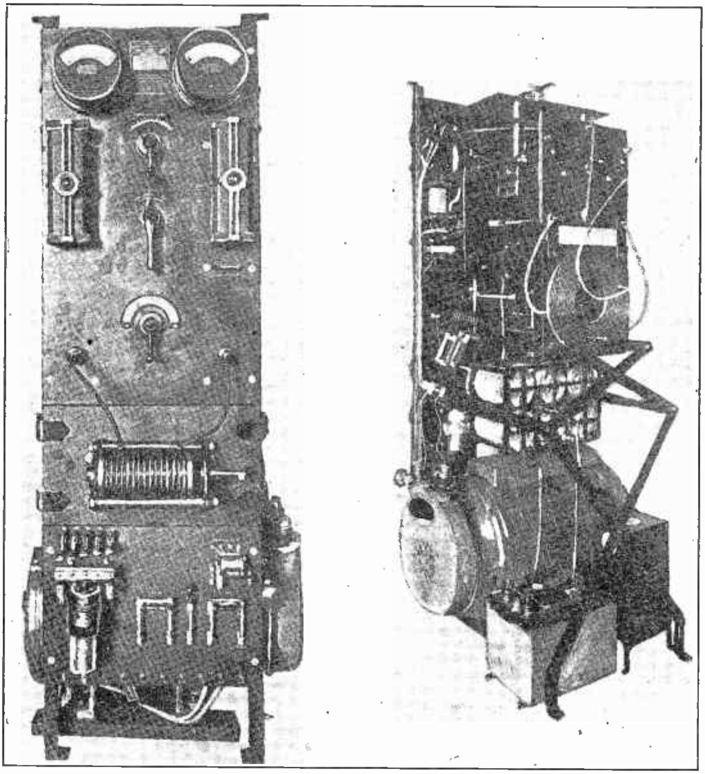


Fig. 477. Front and Rear Views of the RCA 2-K. W. 500-Cycle Spark Transmitter.

with one bank of cells and indicates the current passing through the cells on charge or discharge. When the batteries are discharging, this meter is in series and the pointer shows the ampere-hours consumed. When the cells are charging, the pointer on the meter turns backward, to zero.

The performance of the ampere-hour meter in actuating the circuit breaker is explained in figure 480. During the battery charge the current passes from negative of the line, through the negative side of the switch, and from L to B through the mercury pot and disc inside of the meter. (See figure 558.) In case of an overload from the line, the overload magnet, OL, attracts the left-hand end of the mechanism, M, drawing it upward. This lowers the right-hand end of M, relieving the tension on the handle, through the pivoted right-angle piece of metal, called a *trigger. This is held in place by the pressure against it produced by the toggle joint, T.* The spring, S, then draws the laminated contact switch open as indicated by the dotted lines. C is a carbon contact to prevent arcing. The main circuit-breaker is reset by pushing the handle down and adjusting the trigger by hand. It can also be opened by hand, by knocking the trigger down.

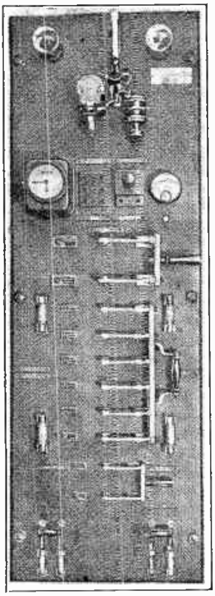


Fig. 478. Electric Storage Battery Company's Charging Panel.

When the battery is fully charged, the meter hand automatically closes the contact at zero, O, and current flows through the low-voltage release magnet,

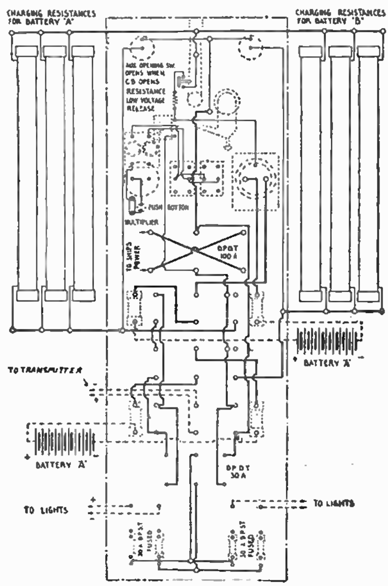


Fig. 479. Rear View of Above Charging Panel Showing Arrangement of Parts and Wiring.

which is in series with the negative side of the battery. The magnetism created by the current through this coil attracts the lower end of the hook-shaped lever, making the opposite end strike the pivoted trigger part of the mechanism, and the main circuit-breaker contact is opened. Simultaneously with the action of the lever, the T-shaped plunger is drawn into the solenoid, closing contacts which place the resistance R directly across the battery terminals. This short-circuit

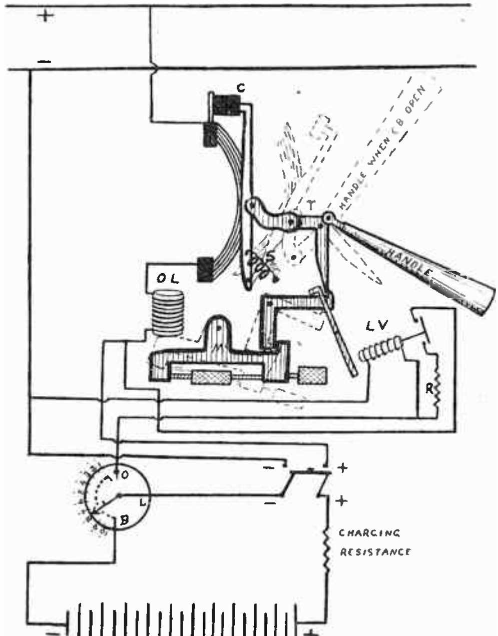


Fig. 480. Sangamo Mercury Ampere-Hour Meter, Showing Connections to Circuit-Breaker.

lasts only an instant. Immediately, with the flow of battery current through the resistance, the ampere-hour meter hand moves away from zero towards the discharged reading of the scale, the contact at O is opened, no current is in the low-voltage magnet, and the T-shaped plunger flies back to its original position.

The low-voltage mechanism will also open the circuit-breaker switch in the same manner in case the generator voltage drops below normal, thus protecting the battery from accidental discharge on the line, and the generator from being damaged or run as a motor by the battery current.

When the six-pole double-throw switch is thrown towards the charging line, the two blades shown at the right-hand end of this switch in figure 476, connect the motor generator to the line, so that the radio transmitter may be operated from the same power line while the batteries are charging. Two small high-resistance lamps are connected so as to maintain a "floating" charge through the batteries while operating the transmitter from the line, in case the ampere-hour meter attachment has tripped the charging circuit. This is to offset any drop that may take place if the batteries are allowed to stand idle. A voltmeter is connected so as to indicate the voltage of either the power line or the storage batteries. Arrangements are also made for supplying the ship's lights from the charging panel. This storage-battery installation is the emergency, or auxiliary power supply, referred to in paragraph 225, and is required by law, as a means of keeping the ship in communication with rescuing parties in case of emergency. By connecting the lights to this emergency power supply, the ship could be kept lighted as long as the storage batteries were in operation, which might be long after the lower part of a vessel, including the dynamo, were flooded.

The panel transmitter, in figure 477, is known as type P-4. The low-potential apparatus is mounted at the lower part of the panel, and the high-potential apparatus above this. The motor-generator consists of a 2-K. W. 500-cycle rotating-armature alternator attached to the shaft of a 4-H. P. 110-volt 2-pole d. c. motor, which is especially constructed to give slight changes in speed on potentials varying between 95 and 115 volts. The generator has an open-circuit voltage of 350, with 140 volts on full load. The generator voltage and the motor speed are controlled by rheostats in series with their field windings, the former at the upper right of the panel, and the latter at the left.

An *automatic starter* controls the starting and stopping speed of the motor, by moving a piston controlled plunger gradually over a series of contact points connected to resistance coils. An adjustment screw provides a feature by which the speed of the plunger can be changed if desired. As resistance is cut out of the motor armature, more current is admitted. The counter emf. of the armature builds up, thus starting the motor smoothly, and protecting the armature windings from burning out by permitting the full current of the line to pass through them. The contact points at R_2 touch at the beginning of this process, but are opened automatically by a mechanical connection to the base of the plunger. This throws this resistance in series with the starter winding, protecting it from overheating, after its magnetic field has been established.

An *electrodynamic brake* is connected to the starter, shorting resistance R_3 across the motor armature upon stopping. This dissipates the accumulated E.M.F., which was the counter emf. of the motor, but when the motor stops, may be discharged as from a d. c. generator. This makes it possible to bring the motor to a standstill within ten seconds, without shock. This is desirable in two-way communication, so that the noise of the motor as it gradually slows down, does not interfere with the reception of signals.

An *overload circuit-breaker* is provided for protecting the motor windings. This has two separate windings on a single iron core. As shown in figure 476, the path of the current is normally through the starter winding, the lower contact of the circuit-breaker, and the upper winding of the circuit-breaker. The lower winding is then not in use. If too great a load passes through the upper winding due to a short-circuit, or other cause, the increased magnetism will raise the switch blade of the breaker, so that it touches the upper contact point. This opens the motor circuits, the starter plunger drops, and no current is then passing through the upper windings on the circuit-breaker, but it passes through only the lower winding, R_1 in series with this winding, and the external circuit.

Both the motor and generator windings are protected by grounded condensers which neutralize any high-potential induction from the high-frequency part of the transmitter. The frame of the motor generator is connected to the earth, as are also the lead tubings through which the wires of the circuit are run.

The circuit including the alternator armature and primary of the power transformer contains the sending key, a wattmeter with a current coil in series and a voltage coil in shunt to the circuit, and a reactance regulator. The reactance regulator, which varies the current, throws the circuit in or out of resonance with the alternator frequency, thus changing the power input of the transformer, and also, by varying the resonance between the primary and secondary of the transformer, affects the total power output of the transmitter. Maximum power is obtained only on the longer wave lengths when the high-potential condensers are connected in parallel.

A low-power resistance is placed in series with the generator field and shunted by a switch. This switch is closed except when it is desired to reduce power below the rating of the transmitter, as when nearing a shore station.

The transformer is of the closed-core, shell type, and is immersed in heavy oil. A safety spark gap is connected across the secondary terminals, protecting the secondary winding and condensers, in case the spark gap is opened too wide, or there is an excessive voltage generated. The potential of the secondary circuit is approximately 12,500 volts, which is used for charging the condensers, at the alternator frequency.

The *high-potential condensers* are usually of the Dubilier mica type, arranged in a bank having an approximate capacity of .01 mfd on the 600-meter wave length. In the original Marconi transmitters of this type the condensers were of the leyden-jar variety, mounted horizontally in the rack near the top of the apparatus.

A synchronous rotary spark gap is mounted on the generator shaft. This has 30 sparking points arranged on the periphery of the disc and rotating between two stationary points. The disc is thoroughly grounded to the earth. A 15-plate *quenched-spark gap* is also provided and may be used instead of the rotary gap, if preferred. Operators often find the rotary gap hard on the condensers. When the quenched gap is used, the rotary gap is cut out of the circuit and a coil substituted to compensate for the reactance of the rotary gap, thus maintaining a balance in the circuit. The clips of the quenched gap are variable, and the voltage of the high-frequency circuit is varied by varying the number of discs in the circuit. As the number of discs is increased, the condenser pressure is raised, due to the back pressure of the gap. When the low-power resistor in the generator field winding is used, the number of discs of the quenched gap is reduced to only two or three, so as to still further reduce the power. The disc on which the points of the rotary gap are mounted carries vanes which serve as a fan to cool the quenched gap when the latter is employed. A pipe leads from the drum in which the rotary disc is enclosed, to the quenched gap.

The oscillation transformer and additional tuning inductance are constructed of copper-strip "ribbon" wound spiral fashion, and coupling is controlled by means of a lever on the panel, which varies the distance between the coils. Connections are made to these coils by flexible leads which are soldered in place after they have been placed at the settings for the various designated wave lengths; and changing from one wave to another, in operation, is accomplished by throwing two single-blade switches which are turned simultaneously by the rotating of a shaft to which they are attached. This switch automatically shifts the settings on the inductance coils, the connections to the condensers, the coupling and the reactance regulator.

The short-wave condensers may be placed in or out of the circuit by opening or closing the switch around them. They are used for obtaining the 600-meter wave length, and cut out for the other wave lengths.

A thermo-coupled ammeter is in series with the antenna. This registers the *effective* value of the high-frequency alternating current traversing the antenna circuit by utilizing a small direct-current voltmeter connected across the terminals of two pieces of dissimilar metals. The meter registers the voltage which is created by the heat set up at the junction of these metals, due to their difference in permeability. The instrument is calibrated to read in amperes. Its range is from 0 to 20 amperes. The type-P-4, 2-K. W. 500-cycle spark transmitter has a daytime transmitting range of about 450 to 650 miles, and of 1,500 to 2,500 miles at night. It is usually installed on vessels of large tonnage.

In figure 476 the antenna ammeter is shown on the antenna side of the inductance. This is preferable to the older method of connecting it in the ground lead. The latter may still be found on old types of standard sets of this type. (See paragraph 503.)

Several ships on which the radio stations are installed and operated by the Radio Corporation of America have replaced the older standard antenna by a single wire. This is easier to handle in putting up and taking down, and is sharper in tuning, cutting down interference both in receiving and transmitting. However, operators report that they notice a decrease in distance covered.

399. The adjustment of the spark gap is important in handling the P-4, as well as other transmitters of similar type.

Quoting from Bucher's *Practical Wireless Telegraphy,* which was prepared for the marine operators of the American Marconi Company: "In the adjustment of the quenched spark discharger, it is to be understood that the *pitch* depends upon conditions of resonance between the open and closed oscillation circuits, as well as upon the voltage of the generator. Careful regulation of the voltage, however, is the principle adjustment and the one to be undertaken first. The operator should select a certain number of gaps, say eight, and follow it by varying the generator voltage. After the set has been tuned for maximum antenna current, the voltage should be slightly readjusted until the spark is clear. It is easily seen that if the note is clear and the secondary circuit is thrown out of resonance, less energy will be withdrawn from the closed oscillation circuit, which will increase the voltage across the gap, the pitch of the note will therefore be destroyed. *The rule to be followed is to tune the set first, and adjust the gap and voltage afterwards* until the note is clear and the wattmeter indicates 2 kilowatts. The synchronous rotary gap is adjusted for a high pitched note by the small brass rod and a knob, which moves the muffling drum carrying the stationary spark electrodes through a 25 degree arc."

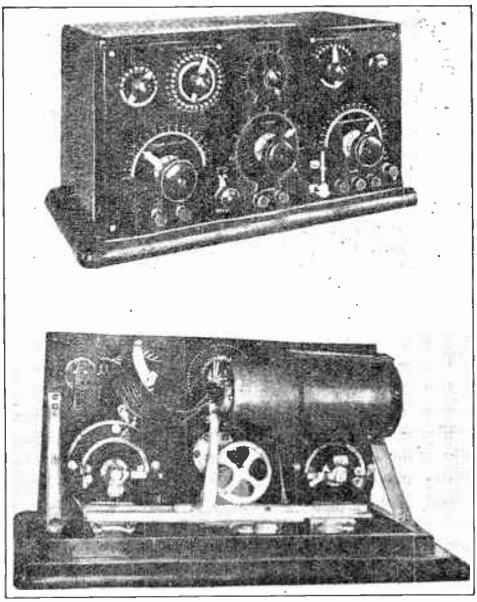


Fig. 481. Front and Rear Views of Marconi Type-106 Receiver.

400. Before vacuum-tube receiving apparatus was installed on ships of the Merchant Marine, the receiving set most frequently encountered by the operator was the old Marconi 106. In the lower view in figure 481, the interior of this receiver may be seen. At the lower center is a

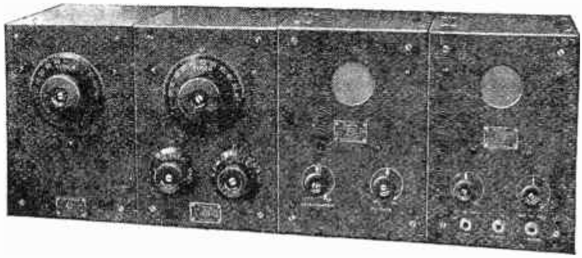


Fig. 482a. RCA Radiola Combination.
(Made by the Westinghouse Co.)

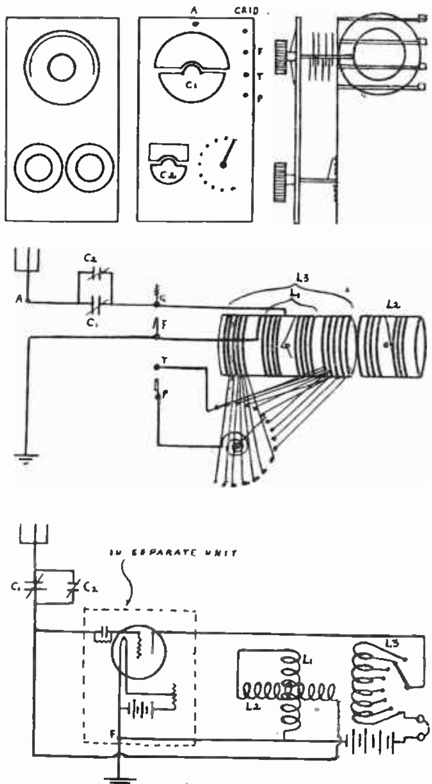


Fig. 482b. Interior of RCA Tuner.

gear which moves the secondary coil in or out of the primary. The secondary taps are run through a flexible tape, which may be seen at the upper left. An end-turn switch, such as illustrated in figure 196, is used here. A smaller one is also employed for cutting off the ends of the secondary in groups as they are tuned out of the circuit. The primary antenna-series condenser, as may be seen at the lower right of the back view, is completely short-circuited by a double-blade contact, when the plates are turned past the point which gives the maximum capacity of the condenser. The secondary condenser, shown at the left of the back view, is cut out of the circuit when its plates have reached minimum capacity. Figure 197 is a simplified diagram of the 106 receiver.

401. Figure 482a is a photograph of the RCA Radiola Combination of which one or more units are sometimes found on ships. The complete combination includes a radio-frequency amplifier, detector, audio-frequency amplifier, tuner and separate coupler. The latter is often omitted. Figure 482b shows the circuit and mechanism of this receiver. On several ships where the RCA 2-K. W. spark transmitter is installed the receiver consists of what is sometimes called the 106-B. This is the old 106 tuning apparatus, with connections for replacing the carborundum detector with a vacuum-tube detector in a separate unit. Sometimes this is regenerative, as indicated in figure 476; and two stages of audio-frequency amplification are generally provided.

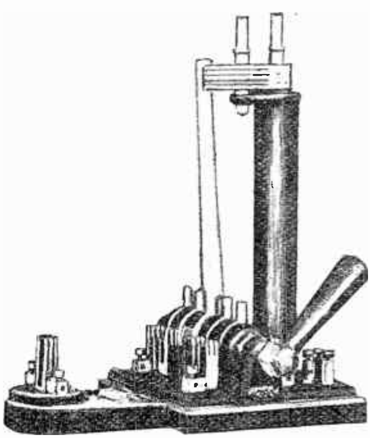


Fig. 483a.
Type-I Antenna Change-Over Switch.

402. The type-I *antenna change-over switch* is constructed for providing automatic change from send to receive position in such a manner as to protect the receiving apparatus from the high power of the transmitter. When the switch blade, in figure 483a, is in the up position, as shown in this photograph, the spring contact

is separated by the blade, and the primary inductance of the receiver is connected to the antenna. The antenna lead-in is attached to the right of the two posts showing at the top of this view by means of a piece of copper tubing, the left-hand post being connected, through copper tubing, to the secondary inductance of the transmitter. The latter is disconnected when the switch is in receiving position.

Throwing the switch blade upward, in receiving position, connects the antenna inductance of the receiver to the antenna and opens the primary circuit of the power transformer, the motor armature, motor starter and generator field. Throwing the switch downward, in transmitting position, opens the contact to the receiving inductance and closes the transmitting circuits.

When the type-106 receiver, with crystal detector, was installed, binding post connections on this switch were em-

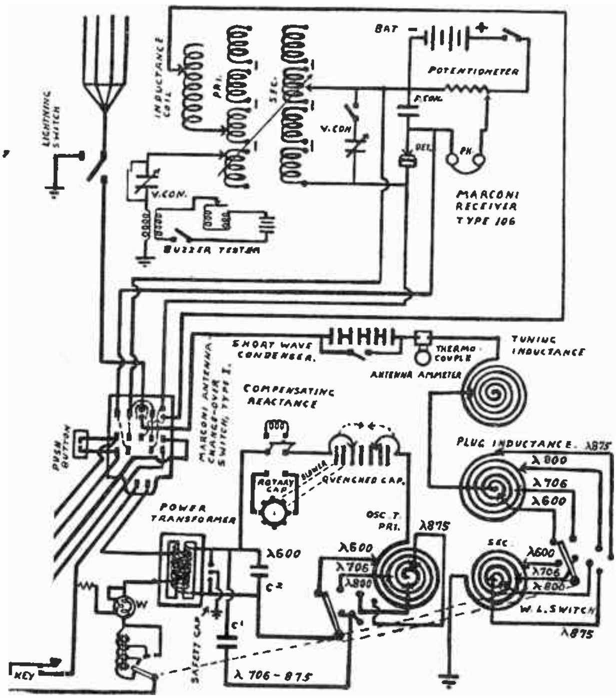


Fig. 483b. Diagram of RCA Type-106 Receiver Showing Type-I Antenna Change-Over Switch Connection for Protecting Crystal Detector and Telephones from High-Power Induction.

ployed to short-circuit the crystal and telephones when the blade was in transmitting position, protecting the receiver from induction of high power.

This switch is installed on the operator's desk, within convenient reach beside the receiver and key, so that he may operate the transmitter and receiver without leaving his chair, after the motor starting switches have once been placed in the proper position for transmitting. The push-button at the left of the change-over switch, in figure 476, is for the purpose of starting the motor from the desk, before throwing the change-over switch into send position, and is especially convenient for remote control, in case the motor generator is placed in an adjoining room.

403. A few RCA spark transmitters of 1 K. W. and ½-K. W. are still in use on ships. They are similar in general appearance to the 2-K. W. set illustrated in figure 477, differing slightly in the arrangement of the meters on the panel, etc. Figure 484 is a front and rear view of the ½-K.W. transmitter, and figure 485 a diagram of this.

The motor-generator consists of a two-pole shunt-wound Eck-type d.c. motor, with a ½-K. W. 120-cycle alternator

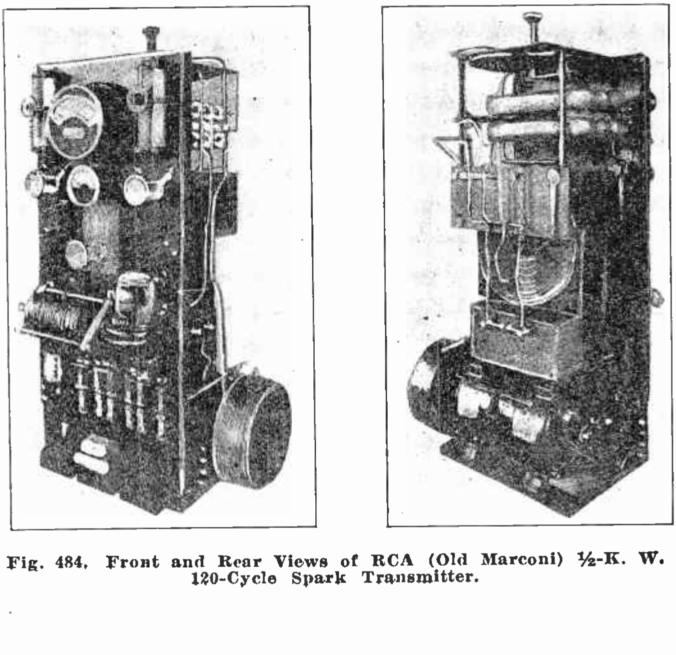


Fig. 484. Front and Rear Views of RCA (Old Marconi) ½-K. W. 120-Cycle Spark Transmitter.

mounted on the same shaft. A Cutler-Hammer single-step automatic starter is mounted at the lower left, on the front of the panel. The usual rheostats and protective condensers are used in connection with the motor generator windings. The no-load voltage of the generator is about 300 and the full-load about 110 volts. The secondary transformer circuit has about 14,700 volts. A wattmeter, having a range from 0 to 750 watts, is mounted at the upper center of the panel, and directly beneath this is the antenna ammeter. The latter is a Roller-Smith hot-wire instrument, having a range from 0 to 10 amperes. The condensers, unless replaced with the mica type, consist of seven tubular leyden jars, mounted horizontally in a rack. The average capacity of each of these is .0015 mfd., and the total capacity of the bank, .011 mfd. A quenched gap is mounted on the panel, with a small motor-driven fan, which blows cool air through a duct into the flanges of the gap, to cool it and cause it to quickly return to its original resistance after each discharge. A synchronous rotary gap is also mounted on the generator shaft. This consists of two stationary electrodes, with six rotating points mounted on a disc and enclosed in a muffling drum. The wave-length changing switch is at the left of the ammeter, on the front

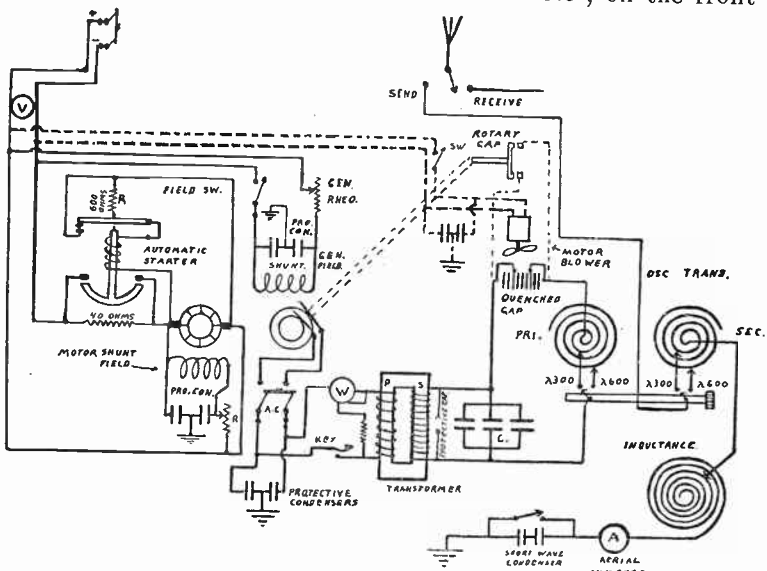


Fig. 485. Diagram of RCA ½-K. W. Spark Transmitter.

of the panel, and the send-receive switch at the right. The lightning switch is not included on the panel, and is arranged separately, in connection with the lead-in.*

404. In several of the modern ship installations an automatic motor starter of different type, known as the magnetic saturation starter, is employed. When used with the type-I antenna change-over switch the usual make and break connections are made to this switch. The principle of the magnetic-saturation starter is shown in figure 486. A hollow frame, F, contains a plunger, P, and a threaded tube, T. The plunger is held above the end of the tube by a brass rod not shown. C represents the coils. When current flows in the coil a magnetic field is set up through the plunger, tube, frame F, and across air gap U. If a heavy current passes through the coil, magnetizing the plunger past the saturation point, some of the magnetic lines of force pass

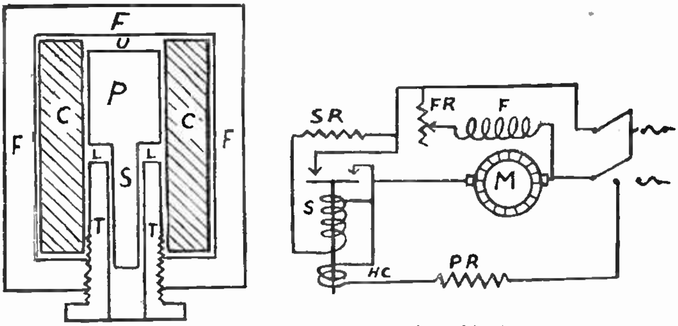


Fig. 486. Magnetic-Saturation Starter.

across air gaps, L, and draw the plunger down. The main coil is in series with the motor. In starting, closing the main line switch passes current through this coil, magnetizes the plunger past saturation, and the air gaps, L, plus the weight of the plunger, hold the plunger down. As the motor picks up speed, generating a counter emf., current is reduced, the magnetic field of the starter decreased, and the lines of force across the gap U lift the plunger up. A brass rod extending through the top of the frame carries a plate

*While this send-receive switch is mounted on the panel of the ½-K. W. Marconi transmitter, it is considered obsolete, and will not be passed by the radio inspectors as a modern ship installation, on the examination for the first-class commercial radio operator's license. It is necessary to use the type-I switch, as in diagram 476, for this purpose.

which makes contact with two brushes, cutting out the starting resistance and connecting the motor directly to the line. The operating coil is also cut out of the circuit, to prevent the plunger from falling while the motor is running, in case the load is increased suddenly. An extra coil is provided, connected across the line with a protective resistance, to hold the plunger in place. Opening the switch disconnects the motor, but the holding coil remains connected until after the line circuit is broken, so the device does not interrupt current when it drops. To cause the relay to trip sooner the tube is turned to the left, withdrawing it from the frame. To trip in later it is turned to the right.

When used with the RCA spark transmitters connections are taken out to the antenna change-over switch, but in such a way as to interrupt current at the relay contact, and cause arcing at the contacts when the motor is stopped.

When installed with the "Simpson" transmitters of the Kilbourne & Clarke Co., a third brush is provided to the last step of the starter, connecting the generator field across the line after the last step has come in.

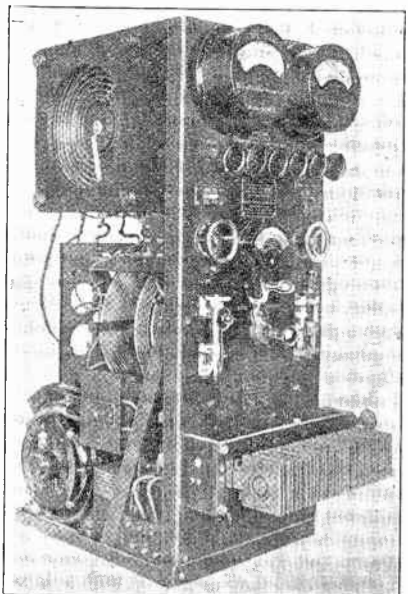


Fig. 487. Wireless Specialty ½-K. W Transmitter, Type Q-S-A-500.

405. The *Wireless Specialty Company*, now connected with the Radio Corporation of America, has for several years manufactured a high grade of radio apparatus, which is sometimes called "Navy Standard," on account of much of it having been installed for the U. S. Navy. It is, however, on vessels of the merchant marine also, and commercial radio operators are frequently called upon to operate it. The Wireless Specialty transmitters follow the same general lines and circuits as the the RCA panel-type transmitters. The con-

struction is somewhat more sturdy, and the control devices somewhat different. In figure 487, the general appearance of the Wireless Specialty ½-K. W. spark transmitter may be seen. A wattmeter and a voltmeter are mounted at the top of the panel. Directly below these are six knobs which are connected to different taps on the antenna loading coils. These are turned to the left to increase the wave length and to the right to decrease it.

The transmitter shown in figure 488a has a wave-changing mechanism consisting of a "steering-wheel" handle, which moves a switch blade to either of the three taps at the upper part of the panel on which the high-frequency portion of the transmitter is mounted. Additional knobs can be seen

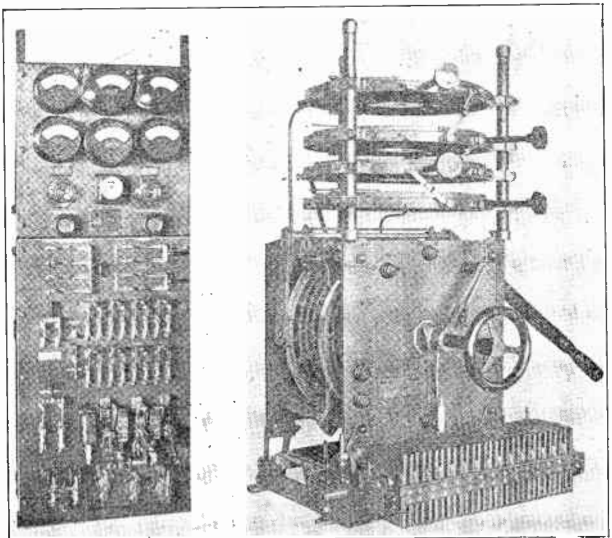


Fig. 488a. The 2-K. W. Transmitter, Type Q-S-2000, of the Wireless Specialty Company.

attached to contacts to the loading coils at the top of this part of the apparatus. The lever at the extreme right manipulates the coupling. At the left is the low-tension control panel, containing seven meters—voltage, current-output, frequency of the 500-cycle generator, and the voltage and current of the storage batteries. Two pilot lamps are placed at the top for lighting the faces of the meters. The generator and motor field rheostats are placed on this panel.

Quoting from literature of the Wireless Specialty Company: "A voltmeter switch is provided for connecting the d. c. voltmeter across either one of the two storage-battery sections during charge, across both in series during discharge, and across the d. c. charging line. An ammeter switch is furnished for connecting the d. c. ammeter in the circuit of either battery during charge, in the discharge circuit, or in the d. c. line. Upon the lower panel are mounted the necessary switches for controlling the charge and discharge of the storage battery, a d. c. main-line double-pole circuit-breaker, a single-pole reverse current release circuit-breaker, automatic starter, and a generator-line field contactor. The magnet coil of the latter is fed from the d. c. main line, and is connected in series with contacts on the antenna switch. It opens the a.c. line and the generator field simultaneously when the antenna switch is in the receive position."

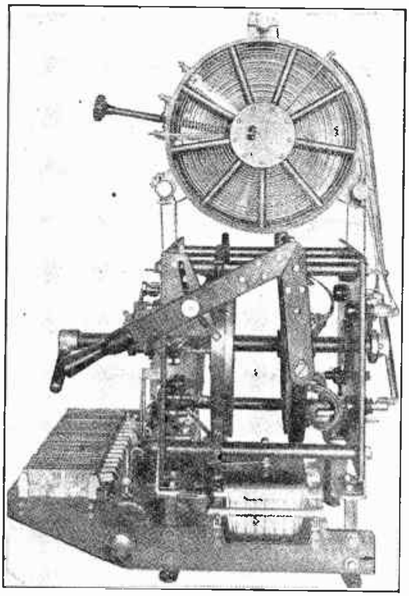


Fig. 488b. Side View of 1-K. W. Navy Standard Spark Transmitter, Showing Mechanism of Coupling Control.

The motor-generator automatic starter, transformer, relay and hand keys, antenna ammeter and lightning switch are supplied for separate mounting. This permits the location of the motor-generator outside the radio room and allows remote control of the station. The motor-generator is a Holtzer-Cabot two-bearing machine, consisting of a 120-volt d. c. shunt interpole motor, driving a single-phase 250-volt 500-cycle inductor alternator at a speed of 2,000 r. p. m. The motor starter is controlled by the operator by means of a push-button switch mounted

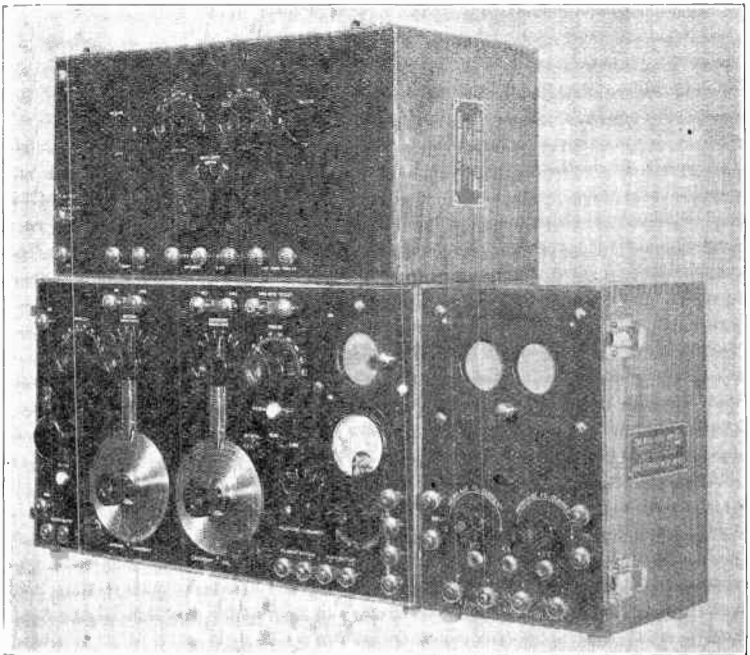


Fig. 489a. Navy Standard Receiver, Type SE-1420, with Audio-Frequency Amplifier and Long-Wave Loading Unit.

on the operating table. The transformer is of the closed-core "shell" type, with the reactance coil mounted in the same case as the transformer.

The spark gap consists of fifteen units of self-cooled type with a switching mechanism for varying the number of gaps in the circuit. The primary transmitting condenser consists of four Faradon .004-mfd. mica units. A continuously variable control of the coupling is provided by means of the lever. Variometer tuning of the antenna on each wave length is arranged so that the tuning of any wave length will not disturb the adjustment of any of the remaining wave lengths, as each wave length is provided with a separate antenna inductance.

406. One of the most used Navy Standard Receivers is known as type SE-1420. This was developed by Professor Hazeltine at the Navy Yard, Washington, D. C., and was the

original neutrodyne receiver, as it was in connection with solving the problem of eliminating noises caused by capacity feed-backs in this set, when tuning to different wave lengths, that Professor Hazeltine is said to have conceived the idea of using neutralizing condensers or coils. The balancing arrangement is indicated in figure 489c. The condenser dials are marked to give readings of wave lengths.

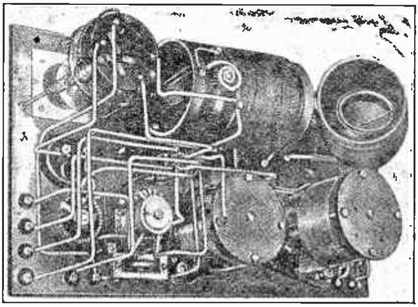


Fig. 489b. Interior of the Navy Receiver, Type SE-1420.

The SE-1420 is now manufactured by the Radio Corporation of America, and installed in the majority of their ship stations. In commercial operating it is called type IP-501.

407. A type of apparatus known as the *impact transmitter* has been in use on the Pacific Coast of the United States for several years. These are manufactured by the Haller-Cunningham Company of San Francisco, and were made also by the Kilbourne & Clark Company. The impact transmitter originated with Sir Oliver Lodge, who did not, however, develop it to a commercial piece of apparatus. The discharge of the condensers is not oscillatory, but rather a sudden and complete discharge of the entire electrostatic charge, in one alternation. This has the electrical effect of striking the antenna system with a *blow*, or *impact*. This energy excites the antenna into oscillation, and it continues to oscillate at its own natural period, without mutual inductance between the antenna and primary coils, and at a rate of damping depending solely upon the antenna resist-

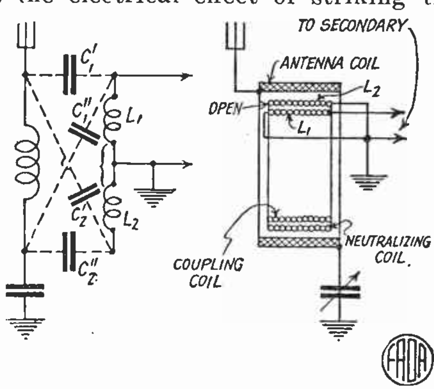


Fig. 489c. Neutralizing Theory of SE-1420.

ance. This makes unnecessary any resonant tuning between the antenna and condenser circuits. The non-oscillating performance of the primary circuit is due to the peculiar construction of it, having an extremely large capacity and practically no inductance, and the arrangement of the spark gap resistance on each side of the single primary turn of wire. The quenched gaps are mounted on a motor shaft and rotated for cooling, making slipping contact to the rest of the circuit. They can be seen at the upper part of the apparatus behind the panel in figure 490a. The antenna inductance and loading coil are visible, but the primary turn does not show.

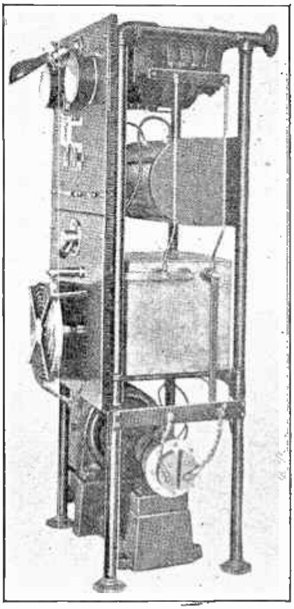


Fig. 490a.
An Impact Transmitter.

408. A transmitter operating on another principle, which is also in use on the Pacific coast, is known as the Simpson *mercury-valve transmitter*. This apparatus is based on the action of the Cooper-Hewitt mercury valve. This *rectifies* the current in the high-potential circuit, and one-way pulsating current is conveyed to the antenna. Quoting words of the

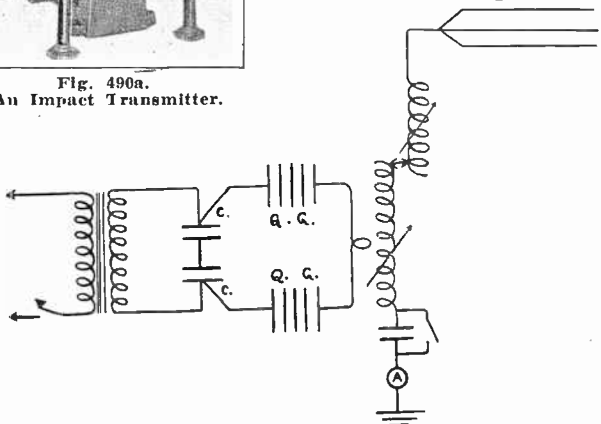


Fig. 490b. Diagram of the Impact Transmitter.

the inventor, Mr. F. G. Simpson, "The antenna circuit comprises the overhead wires A, variable inductance L, spiral inductance W, variable condenser C, and the ground. The system is so proportioned and adjusted that when the antenna is fully charged the mercury valve closes, that is, its resistance rises to a point sufficient to prevent the forma-

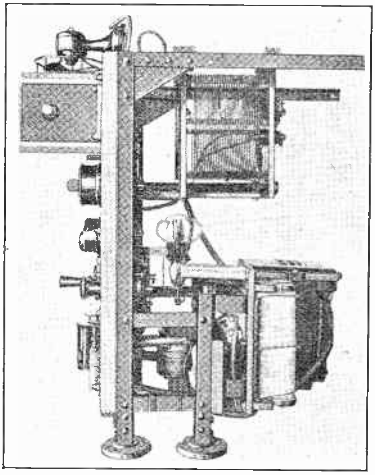


Fig. 491a. Photograph of the Mercury-Valve Transmitter. (Courtesy Capt. E. W. Stone.)

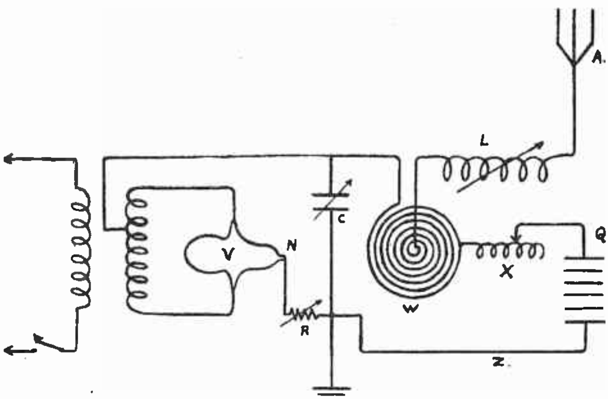


Fig. 491b. Diagram of Mercury-Valve Transmitter. (Stone.)

tion of an arc across the spark gap Q. G. The energy is thus delivered to the antenna in static form, but radiation cannot take place until this energy has been set into oscillation. For this purpose what is designated as a converting trigger is utilized. This consists of variable condenser C, conductor Z, special Simpson spark gaps Q, Inductance X, and a small portion of the inductance W. The condenser C, and a small portion of coil W are common to the antenna and the converting trigger. When the antenna is fully charged, the pressure breaks down the resistance of the spark gaps Q and a portion of the current flows through the spark gaps in the converting trigger and is set into oscillation. The converting trigger is not a circuit so as to permit current to pass through it except at the instant the resistance of the spark gap is broken by overflow from the whole antenna system. It ceases to be a circuit substantially as soon as the energy is set into oscillation, because the circuit is so proportioned that the original resistance of the spark gap is rapidly regained, with the result that in its best operating condition the action of the trigger is quenched after one-half of one oscillation. This increases to a maximum of 2.5 oscillations if the transmitter is improperly adjusted or not in normal operating condition. The equilibrium which existed in the antenna, before the trigger action of the circuit C, Z, Q, X and W began, has thus been disturbed and the antenna then oscillates in its *own natural period* until the energy is usefully dissipated in the form of waves, when the antenna is again charged from the supply circuit and the process repeated. During the stage of radiation, the antenna is cut off from the source of supply because the resistance of the mercury valve V varies inversely with the current flowing through it. When the pressure between the terminals of the condenser equals the charging pressure no more current will flow into it. As this point is reached the resistance of the mercury valve is increased. Consequently, when the current is at a minimum the resistance of the valve is at a maximum. The converting trigger is so proportioned in its relation to the mercury valve V, the patented Simpson spark gaps Q, the proportion of capacity, inductance and resistance, and the careful adjustment of the leads of the spark gaps to the antenna at the nodes of potential, that under normal conditions it will go out of action instantly after fulfilling its function of rendering oscillatory the static energy of the condenser. Any continued action on the part of the trigger thereafter would cause energy, which normally ought to be employed in antenna radiation, to be dissipated in the spark gap resistance."

The impact and mercury-valve transmitters are each commonly constructed in 2-K. W. size, although the Simpson transmitter is on the market in a ½-K. W. type also. The Simpson-Mercury-valve transmitter has been installed on several vessels of the U. S. Navy.

409. On all of the larger and more expensively equipped passenger liners vacuum-tube transmitting and receiving apparatus is installed. The transmitter is usually equipped for both telegraphy and telephony, and the receiving apparatus includes an equipment for furnishing loud speaker entertainment to the passengers in the saloon. There are generally two or more receiving systems, so that routine work may be carried on at the same time that broadcast reception is taking place. Separate antennae are provided for this arrangement.

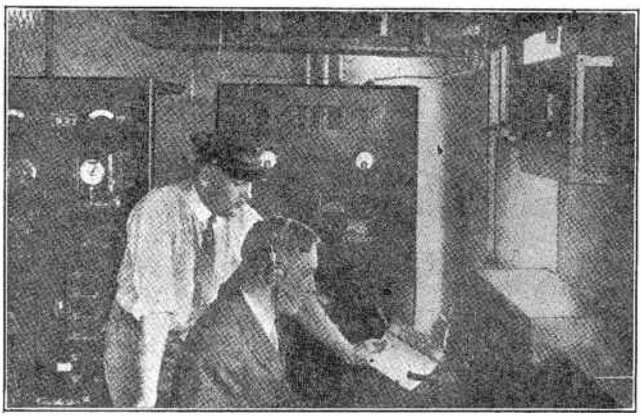


Fig. 492. The Radio Room of the S. S. Greater Detroit, Equipped with a 200-Watt Tube Transmitter.
(From World Wide Wireless, published by and for the employes of the Radio Corporation of America.)

Tube apparatus is also gradually replacing the spark installations of the Radio Corporation of America, and some other radio companies, on the better class of freighters. In several cases the Radio Corporation has converted the old 2-K. W. spark transmitter, adapting it to tubes. This is

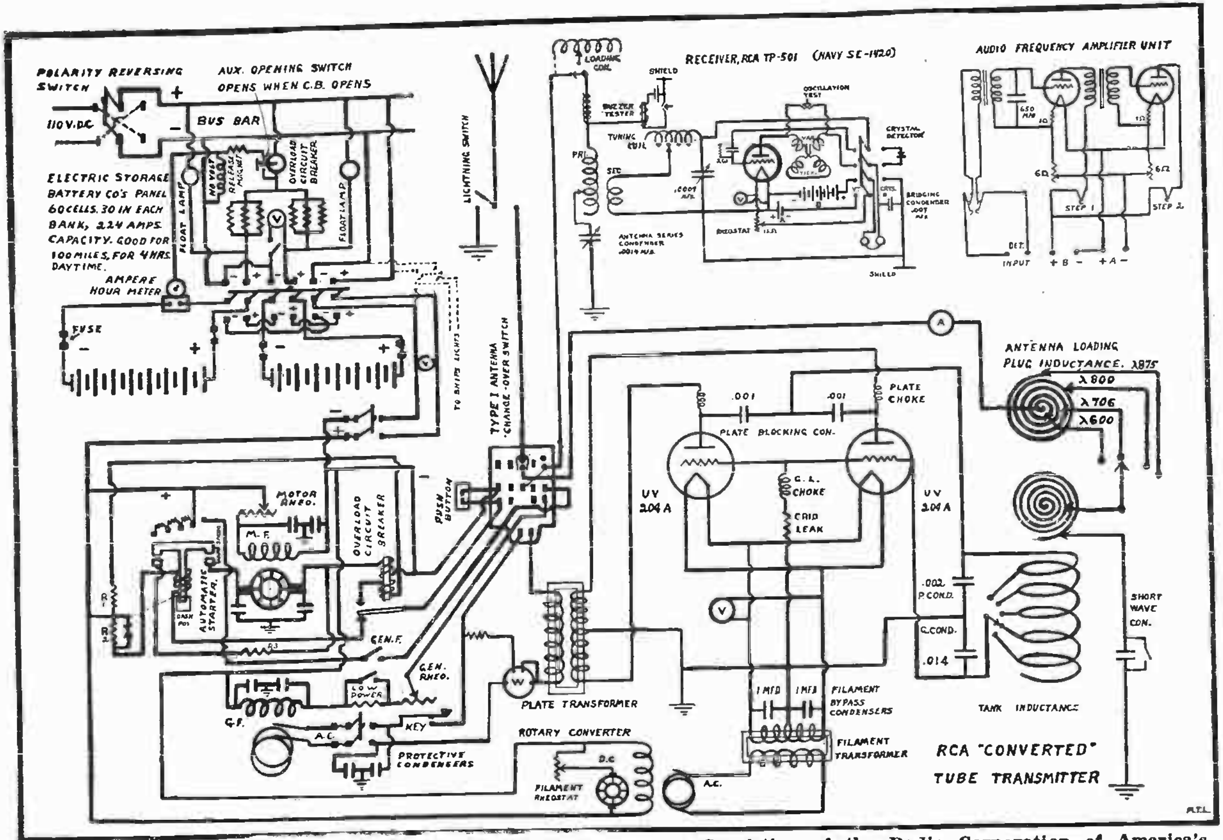


Fig. 493. Complete Wiring Diagram of Modern Ship Installation Consisting of the Radio Corporation of America's Converted Tube Transmitter, Type ET-3628. Electric Storage Battery Company's Charging Panel and IP-501 (SE-1420) Regenerative Receiver with Two Stage Audio-Frequency Amplifier and Long-Wave Loading Unit.

known by the type number ET-3628. The Navy Standard receiver shown in figure 489a is generally used with this installation. The same power circuit and storage-battery auxiliary are retained, as is also the type-I antenna change-over switch. Two UV-204-A 250-watt tubes are used, serving

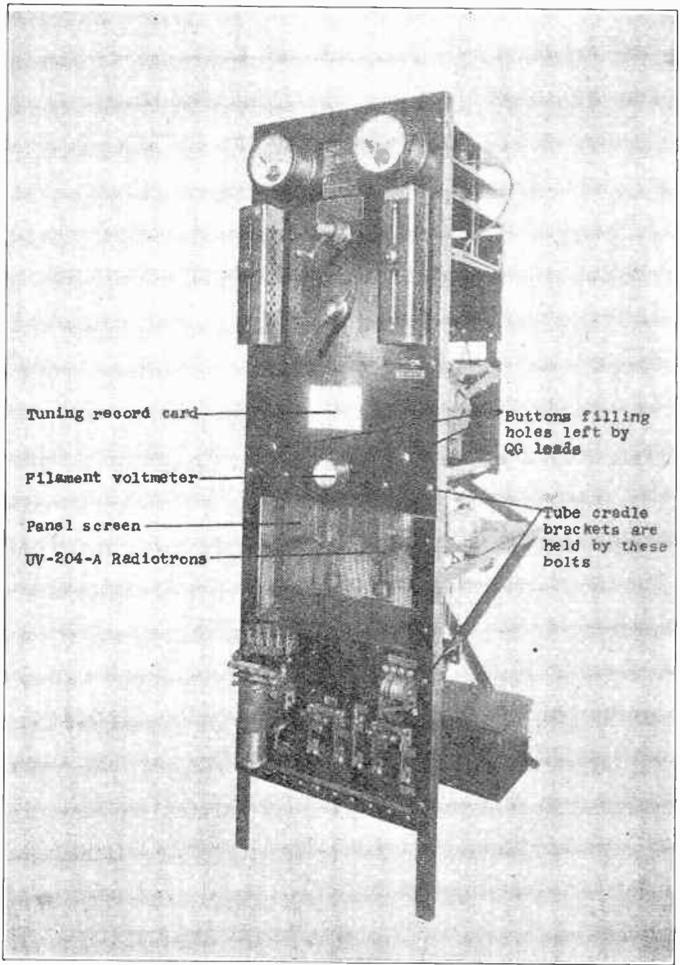


Fig. 494a. Front View of RCA Transmitter Type ET-3628.

alternately at opposite terminals of the power transformer secondary, in producing a. c. modulated continuous waves.

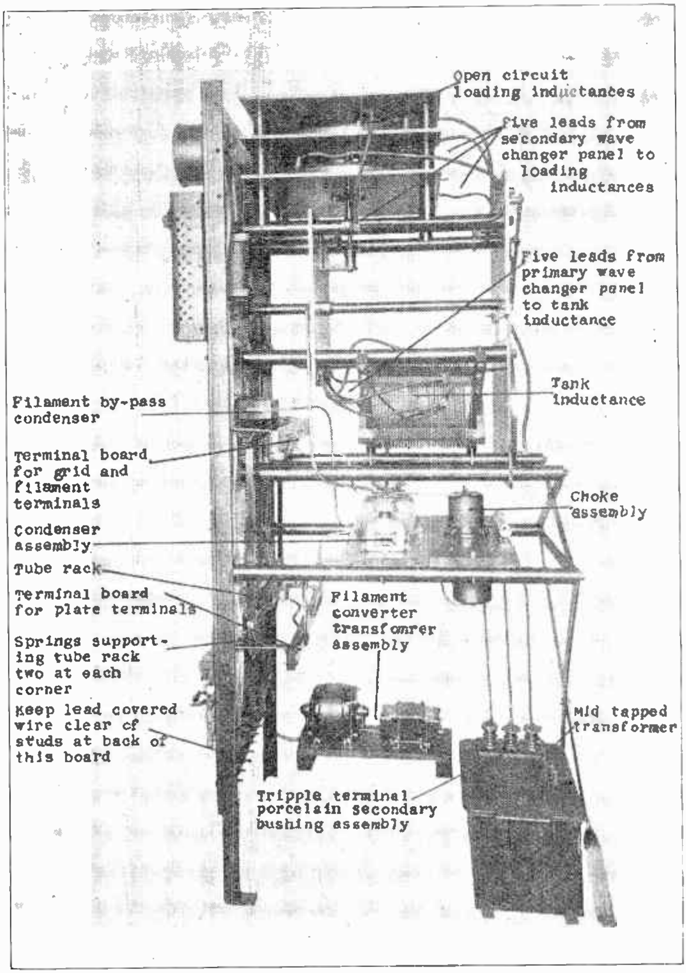


Fig. 494b. Side View of RCA Transmitter Type ET-3628.

The oscillatory circuit is a modification of the Colpitts, with the grid voltage varied by means of a capacity feedback from the plate condenser. A new center-tapped power transformer may be provided for plate supply or the old transformer may be used, connecting the secondary pies in parallel, as in figure 494c.

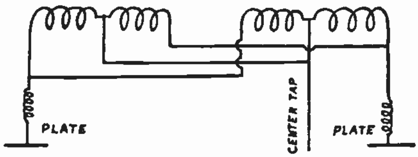


Fig. 494c. Manner of Utilizing Old Spark Power Transformer for Center-Tapped Plate Supply.

410. Two more recent types of vacuum-tube transmitters, manufactured by and installed on vessels of the Radio Corporation of America, are models ET-3626 and ET-3627. The model ET-3626 is designed for installation on vessels requiring reliable service at ranges up to 1,000 miles, such as first class passenger vessels, large private yachts, etc. The power supply consists of a d. c. motor-generator requiring 2-K. W. input. The motor has a power rating of 2¼ K. W. and the generator a rating of 1 K. W., at 1,000 volts. Current for lighting the filaments is provided by slip rings on the motor. The master-oscillator system is employed with one UV-211 Radiotron as a master oscillator, one UV-211 Radiotron as a bias rectifier and six UV-211 Radiotrons as power amplifiers. These tubes use the thoriated filament, which consumes low power for results obtained. The six UV-211 tubes in the power amplifier have an output of approximately 100 to 125 watts each. The use of a number of small tubes in the power supply instead of one or two larger ones has several advantages, among which is the ability to operate the set at reduced power with less than the normal number of tubes. The smaller tubes also make possible the use of lower plate voltage than is needed with high-powered tubes. The wave-length range is 300 to 800 meters, and 1,800 to 2,400 meters. Two separate coils are provided, one for each wave-length band. Tuning is simple, being accomplished by placing the wave-band switch in the desired position and setting two calibrated variometers for the wave length desired. The apparatus is designed for telegraph only, arrangements being made for straight CW and ICW. The interrupted continuous waves are obtained by use of a chopper driven by a ⅛-H. P. motor. A separate

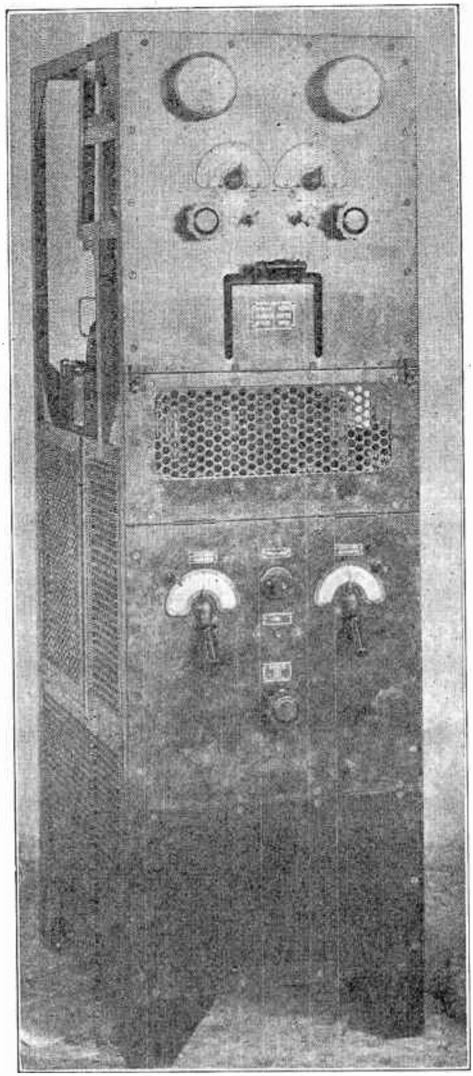


Fig. 495. Photograph of RCA Vacuum-Tube Transmitter, Model ET-3626.

control unit, containing the filament rheostat, filament voltmeter, and start and stop push-buttons, is mounted on the operator's table. The transmitting range is from 1000 miles daytime to 2000 miles at night on CW, and about 300 to 500 miles daytime for ICW, with about twice as far at night.

411. The Model ET-3627 is designed for coastwise service, such as private yachts, etc. It employs the master-oscillator principle with one UV-211 Radiotron for oscillator and two UV-211 Radiotrons for power amplifiers. Power is obtained from a d. c. motor-generator, providing 1000 volts for the plates of the tubes, and filament heating energy through slips rings on the motor. Special equipment for operation from a 32-volt power supply can be supplied if desired. The wave-length range is from 600 to 960 meters, and the transmitting range approximately 500 miles daylight with CW and 200 to 300 miles with ICW, and about double this distance in the night. This transmitter is only 38 inches high, 20 inches wide and 21 inches deep.

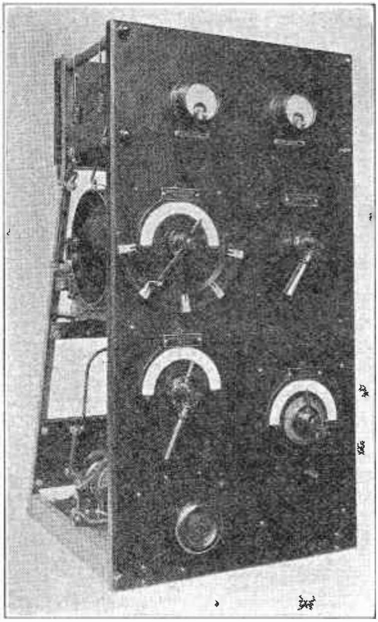


Fig. 496. RCA Transmitter, Type ET-3627.

The circuit of the ET-2637, or ET-3627-a, is the same as shown in figure 503b, minus the telephone attachment, and having a chopper shunted around the grid condenser and grid leak for ICW. The master-oscillator variometer is calibrated for wave-length adjustments, and in tuning the apparatus, this is set for the desired wave length, and the antenna variometer then adjusted until the antenna ammeter indicates resonance.

412. In figure 497 is shown a mechanism known as the Leach Break-in Relay. This takes the place of the hand-thrown antenna change-over switch in many modern ship in-

stallations, including some of the Radio Corporation of America. The drawing is self explanatory. The advantage of this type of relay is that while the operator is sending he can *hear* from outside at the same time between his dots and dashes. Thus if a receiving station with whom he is in communication misses a word, he can signal the transmitting station by sending a long dash. This calls attention, and the transmitting operator can then listen to the other operator learning what he missed, and communication continues. This makes it unnecessary to repeat the entire

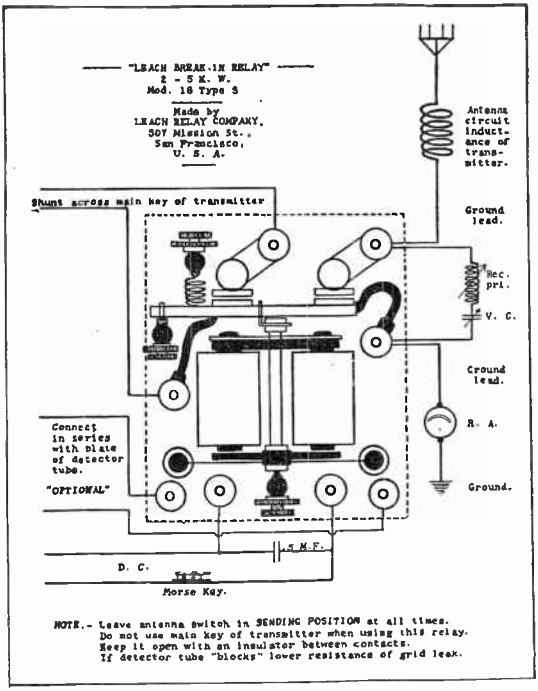


Fig. 497. Leach Break-in Relay.

message, as is done with ordinary types of change-over switches. The relay connects the antenna to the receiver when the key is raised and disconnects it when the key is pressed.

413. With the tendency away from the old spark transmitters, the low-powered arc is found to provide the undamped waves desired without the expense connected with

handling the transmitting vacuum tubes, which are sometimes accidentally blown, and which, after all, have a limited life. Many sturdy installations of arcs, arc panels, etc., are now in use on vessels plying the Pacific coast of the United States.

The Federal Telegraph Company of San Francisco is installing combinations of arc and emergency spark, such as shown in figure 498.

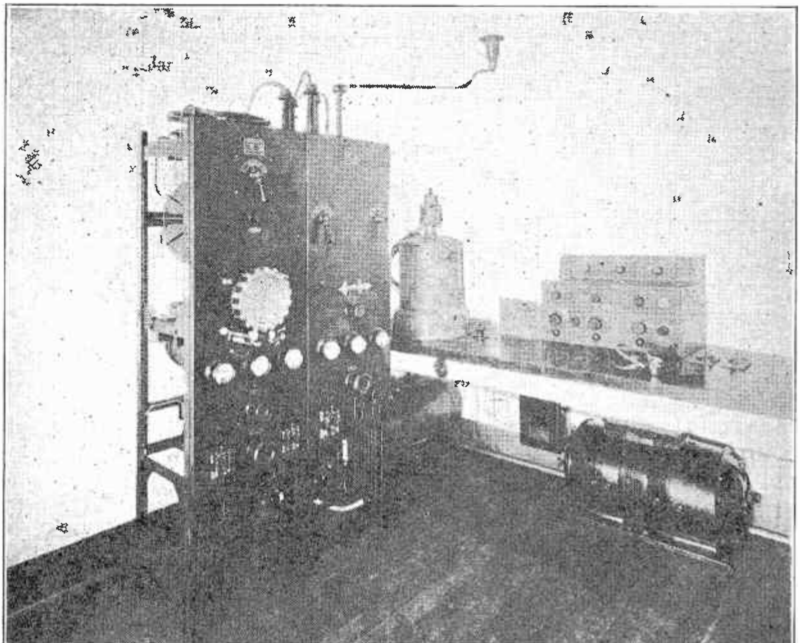


Fig. 498. Combined 2-K. W. Arc Transmitter, Type AM-3914, and ¾-K. W. Spark Transmitter, Type CM-1109, Typical Ship Installation of the Federal Telegraph Company.

The 2-kilowatt arc is of the usual type. The back-shunt signaling method is employed. The antenna inductance, wave-changing switch, meters, signaling system, water pump, etc., are mounted on an arc control panel. Standing beside this control panel is a novel type of spark transmitter made by the Federal Telegraph Company. This employs a rotary gap which may be seen at the center front of the panel. The manner in which this differs from previous types of spark sets is that there is no motor-generator used with it. Instead, the d. c. from the ship's supply line is passed through a rotary interrupter, producing a one-way pulsating current. This passes through a low-ratio transformer, and thence through a high-ratio transformer. The high-potential alternating current thus obtained is used to charge the primary oscillatory condenser, which is discharged through the rotary spark gap and an inductance, producing the radio-frequency oscillations. The use of a synchronous gap gives a sharply tuned clear note.

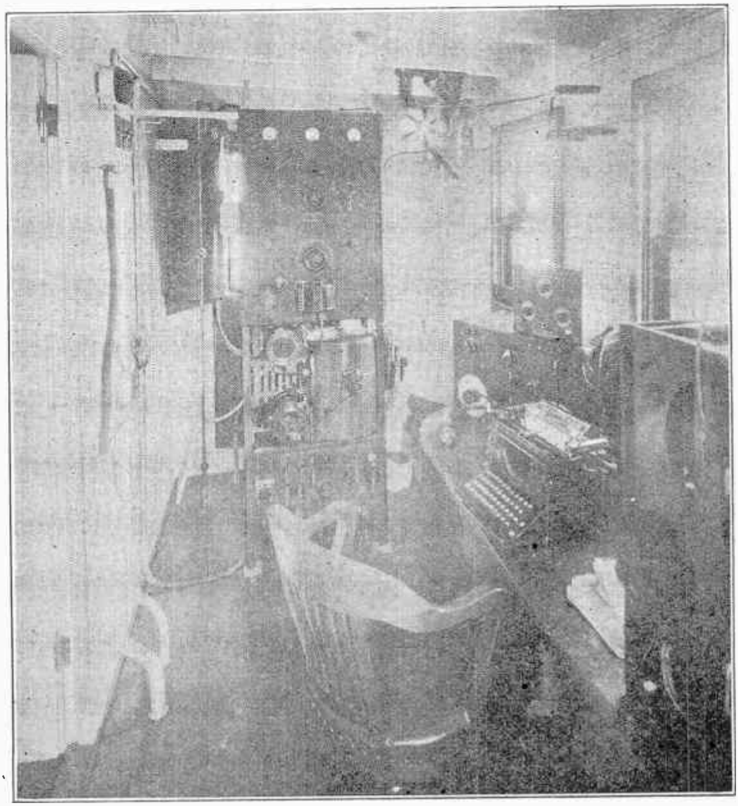


Fig. 499. Ship Station of the Independent Wireless Telegraph Company on Board the S. S. Robert E. Lee.

The wave length of the arc transmitter is from 1,500 to 2,500 meters, when used with an antenna having an effective capacity of not less than .00064 microfarads, and the range is from 2,000 to 5,000 miles. The wave length of the spark set is from 600 to 950 meters, with a range of a few hundred miles. It is used for calling on these wave lengths, SOS, etc.

414. The Independent Wireless Telegraph Company of Philadelphia, New York, etc., is also putting out a marine arc transmitter which they install on a number of ships. In this case the arc converter and control panel are combined into one complete apparatus. The back-shunt signaling system is used, and a chopper is included for communication with stations not equipped for receiving continuous waves, and for SOS. The chopper can be seen at the upper left of the arc converter in figure 499.

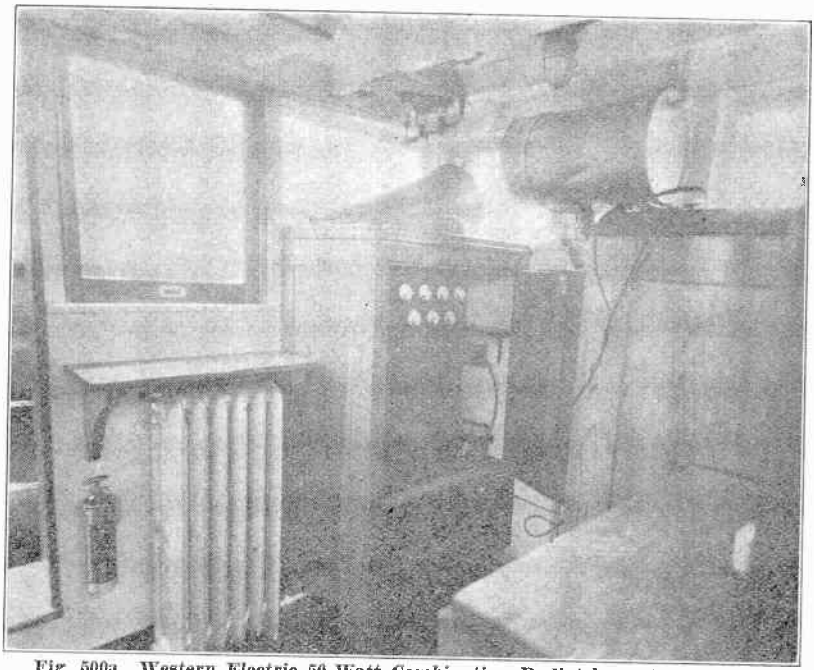


Fig. 500a. Western Electric 50-Watt Combination Radiotelegraph and Telephone Transmitter, Type I-1-A, Enclosed in Protecting Cabinet, on Board a 75-Foot Patrol Boat of the U. S. Coast Guard.

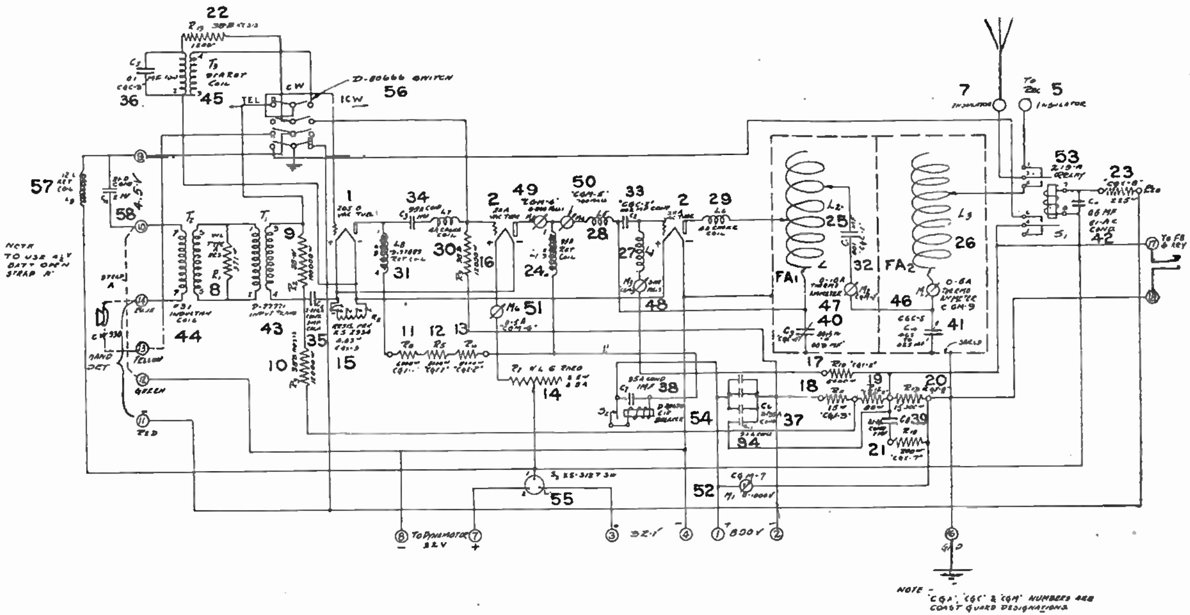


Fig. 500b. Diagram of Coast Guard Transmitter, Model T-1-A.

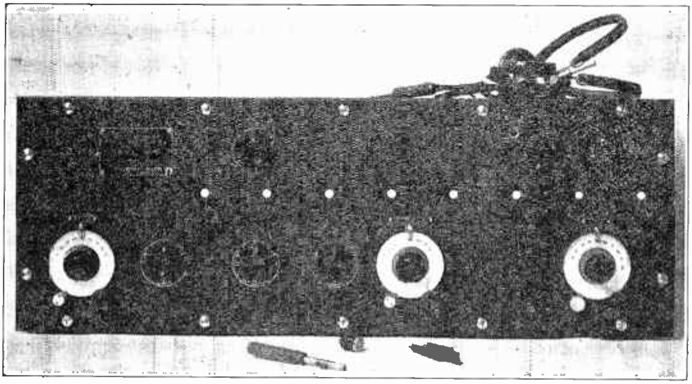


Fig. 501A. Type CGR-1-A Receiver, made for the U. S. Coast Guard by the Western Electric Co.

415. No treatment of marine radio equipment is complete without including that of the U. S. Coast Guard. While the Coast Guard operates Revenue Cutters and keeps a lookout along the shores for any activities which might be harmful to the country, its main business is life saving. The equip-

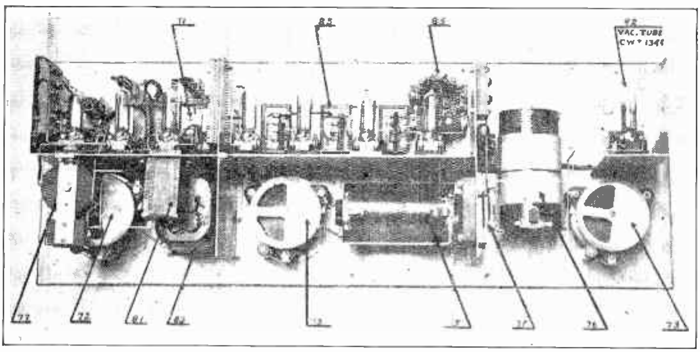


Fig. 501B. Rear View of Western Electric Type CGR-1-A Receiver.

ment consists of a large number of shore stations where radio operators are kept on continual watch listening for messages of trouble from the sea, and small motorboats, self-righting, self-bailing life boats, and several cutters carrying life-line-shooting guns and all kinds of supplies needed for care and resuscitation of the partly drowned. When a passenger ship, freighter, or pleasure yacht within range of the

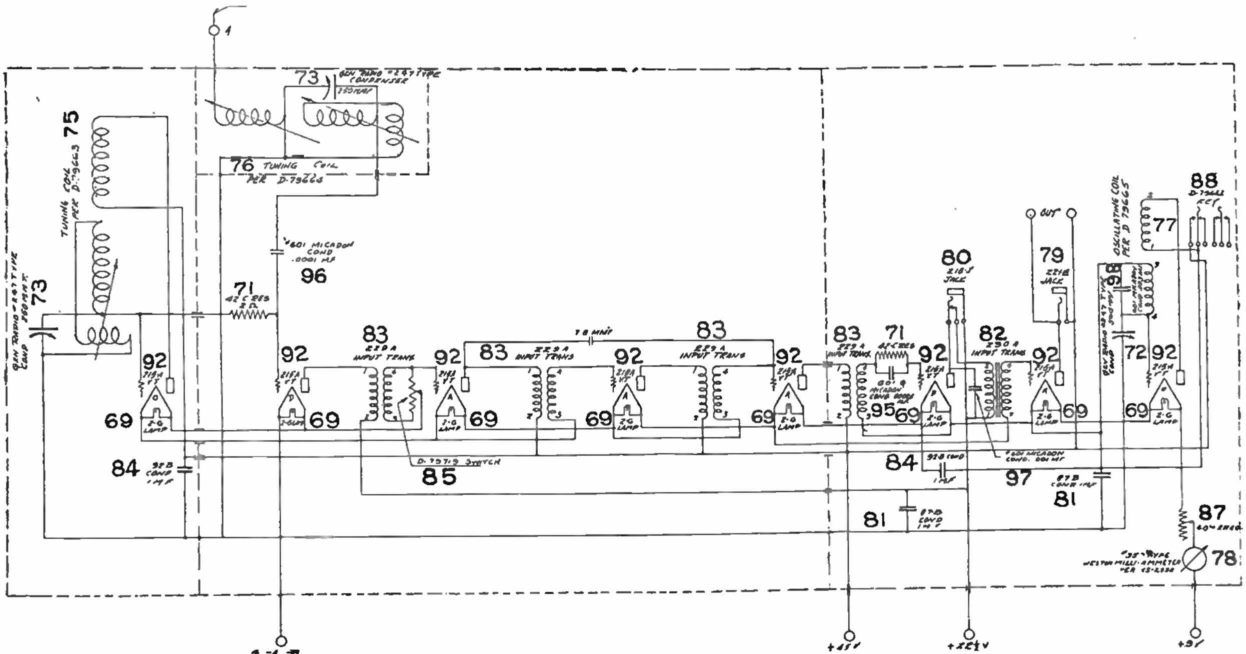


Fig. 502. Diagram of Western Electric Type CGR-1-A Superheterodyne Receiver.

United States coast sends out an SOS, it is probable that they will be assisted or rescued by the Coast Guard.*

The characteristics of the radio installations of the Coast

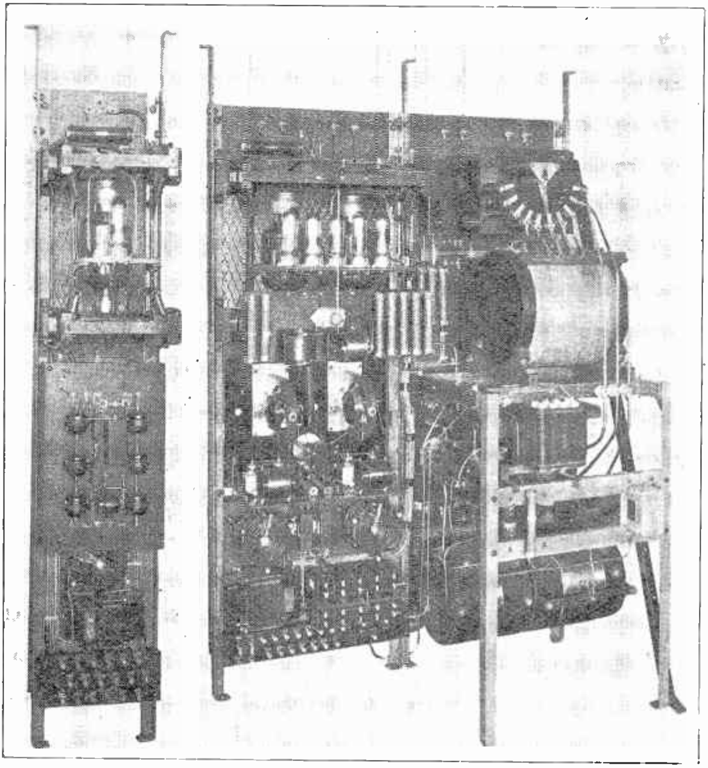


Fig. 503a. 2-K. W. Radiotelegraph and Telephone Transmitter Manufactured by the General Electric Company for the U. S. Coast Guard. (Rear View.)

Guard are exceptional sturdiness and compactness. For the smaller boats long-distance transmitting range is not required, so comparatively low power may be used. Most of the transmitters are arranged for both telegraphy and telephony.

The apparatus illustrated in figures 500a and 500b employs

*For information, see *Functions, Duties, Organization and Equipment of the United States Coast Guard,* free at the Government Printing Office, Washington, D. C.

the Colpitts oscillator circuit with Heising modulation using two 50-watt tubes, and one 5-watt tube for the speech amplifier. The power supply consists of a dynamotor for the plates, a filament lighting supply taken from the ship's 32-volt storage battery, and microphone current from either a separate battery or from the 32-volt battery in connection with a filter circuit. The frequency band is between 1700

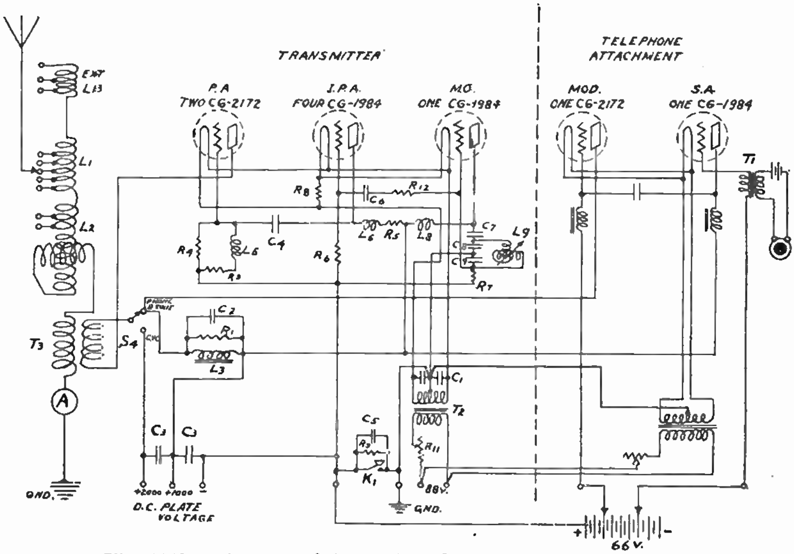


Fig. 503b. Diagram of Coast Guard Transmitter, Model T-2.

and 2500 kilocycles (176 to 120 meters) and the distance range about 100 miles for telegraphy and 50 miles for telephoning.

416. The receiver used in the installation with the type T-1-A transmitter is shown in figure 501a. The black numbers in 501b and 502 match, the diagram serving to explain the photograph of the rear view of the receiver.

A 2-K. W. combination telegraph and telephone apparatus is carried on the larger cutters of the Coast Guard. One of these is shown in figure 503a. It is known as Model T-2. A master-oscillator circuit is used, one CG-1984 50-watt tube for the master oscillator, four of the same tubes as intermediate amplifiers, and two CG-2172 1-K. W. tubes as main power amplifiers. The frequency bands covered are from

107 to 187 kilocycles (2800 to 1600 meters), and 312 to 500 kilocycles (960 to 600 meters). A four-position signal switch on the panel provides "low" and "high" CW, Tone telegraphy, and telephony. The tone telegraphy is carried through the telephone speech-frequency circuit by means of substituting a tone alternator for the microphone.

The signal switch performs several functions. When placed on "Low CW" it connects the main power amplifier tubes to one-half normal plate voltage, and when placed on "high CW" puts the main power amplifier on full plate voltage. On "Tone" position it starts the tone alternator in the telephone attachment and lights the filaments on the modulator and speech amplifier tubes. The same operations are carried out on "Phone" except that the microphone is connected in circuit in place of the alternator.

417. A new type of calling apparatus has recently been designed and put into use in the Coast Guard. It consists of the CGR-9 Transmitter attachment and the CGR-10 receiver attachment. These attachments have been designed to provide the Coast Guard with selective signaling system to be used in connection with the model T-1-A transmitter and the type CGR-1-A Radio Receiver for intercommunication between vessels. By means of the signaling system the station at which the transmitter attachment is installed will be able to call individually any vessel equipped with the receiver attachment, or all of these vessels simultaneously, by a single operation of the calling key which constitutes the transmitter attachment. The transmitter consists of a selector key which may be adjusted to send out any desired call with a single operation of its operating lever, and is connected to the radio transmitter in parallel with the telegraph key and controls the output of the transmitter in the same manner. The various code combinations are set up on the selector key by means of three small levers, and the key operated by pulling the large lever at the right down as far as possible and releasing it.

The receiving attachment is shown in figure 505a and 505b. All of the apparatus is mounted on a sheet-brass panel which is suspended by springs within a cabinet which is of the same height and depth as the Coast Guard type CGR-1-A receiver. The input terminals of the signaling attachment are connected to the output terminals of the type CGR-1-A receiver. Connections are made so that the storage battery used with the receiver may also light the 215-A tube in the signaling attachment. The output from the radio receiver goes directly to the grid of the vacuum tube through the D-80952 input transformer which is tuned to the modulating frequency of the model T-1-A transmitter. A relay is inserted in the plate circuit of this vacuum tube. It is operated with a large negative grid-biasing potential

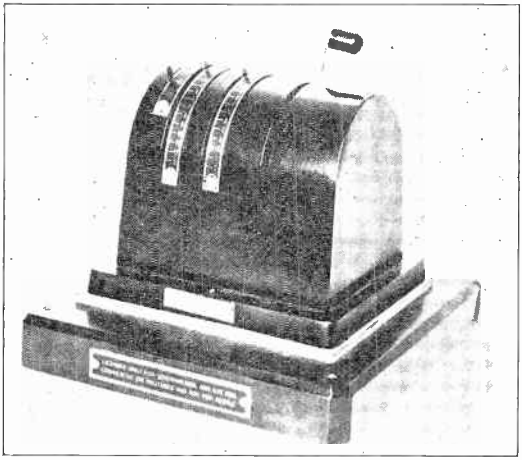


Fig. 504a. Type CGR-9 Radio Transmitter Signaling Attachment manufactured by the Western Electric Company for the U. S. Coast Guard.

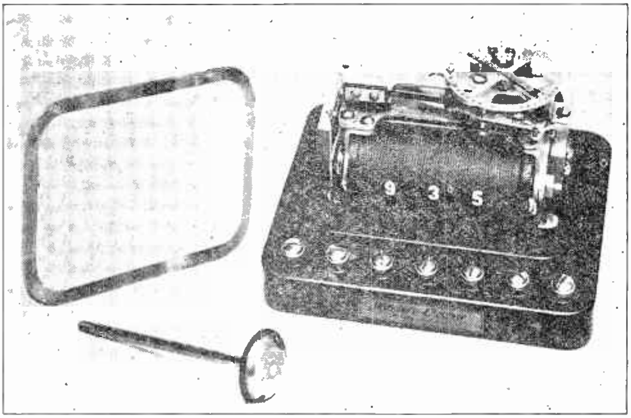


Fig. 504b. Interior of Transmitter Signaling Attachment, Type CGR-9.

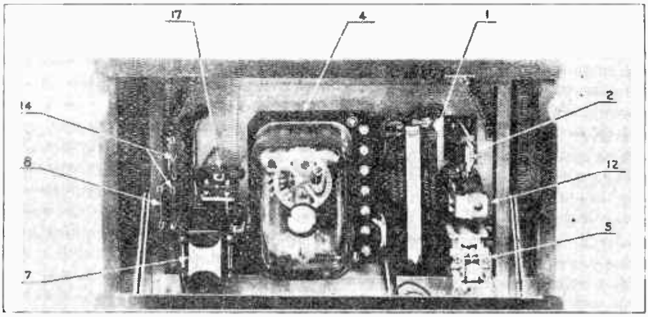


Fig. 505a. Type CGR-10 Radio Receiver Attachment manufactured by the Western Electric Company for the U. S. Coast Guard, Cover Open.

so that the normal plate current is only .1 to .2 milliampere. Upon reception of a signal this is increased to .5 milliampere, or more, which is sufficient to operate the relay. This relay

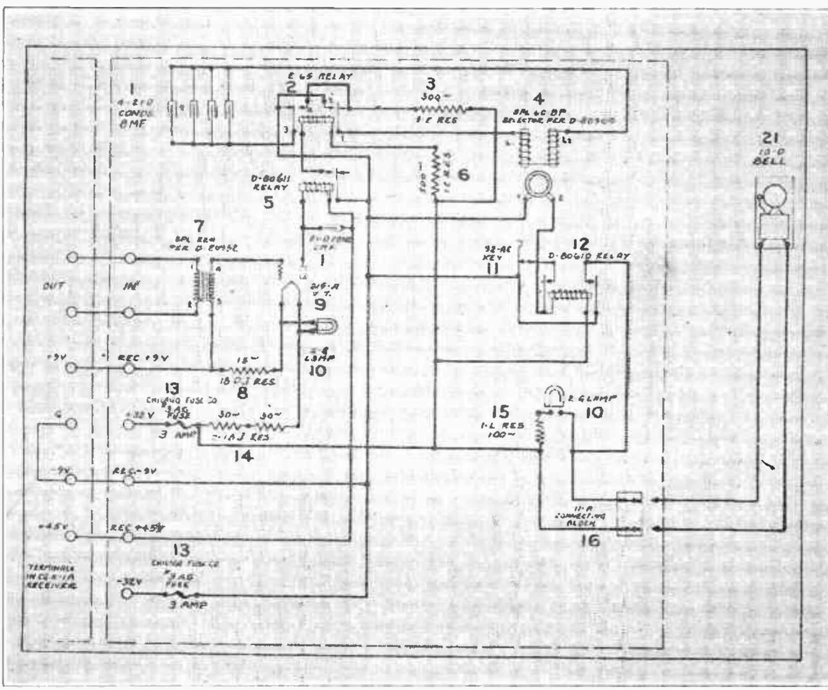


Fig. 505b. Diagram of Type CGR-10 Radio Receiver Attachment.

remains operated for the duration of the signal, releasing when it ceases. The operation of the D-80611 relay closes the circuit through the winding of the E-65 relay, and operates the D-80900 selector, which is the heart of the apparatus.

The selector consists of a mechanism unit mounted upon a magnet unit, enclosed in glass for protection. The magnet windings are connected to a source of direct current, in this case the 32-volt storage battery of the installation. With

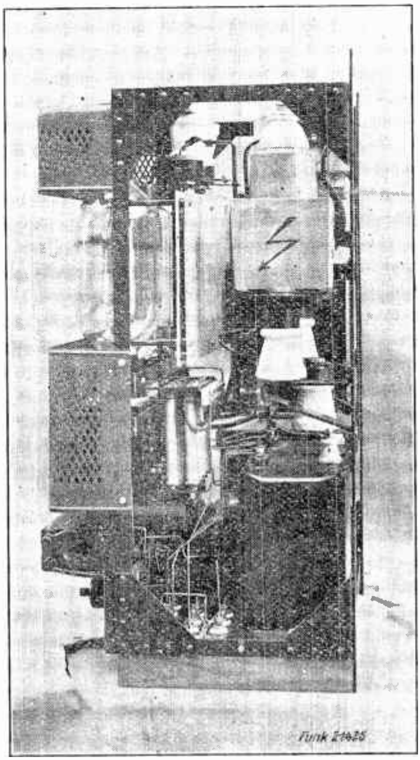


Fig. 506. Modern Telefunken Ship Set For Radiotelegraphy or Telephony.*

*Photograph sent from Berlin to the author by the Telefunken Company especially for publication in this text book.

this relay in either position a circuit is made through the condenser and windings of the selector. The source of current being a steady d.c., no current will pass through the condenser. When the reversing relay is alternately operated and released, however, the repeated charging of this condenser in opposite directions sends pulses of current through the windings of the selector, which gives a rocking motion to the selector armature and operates a ratchet on the code

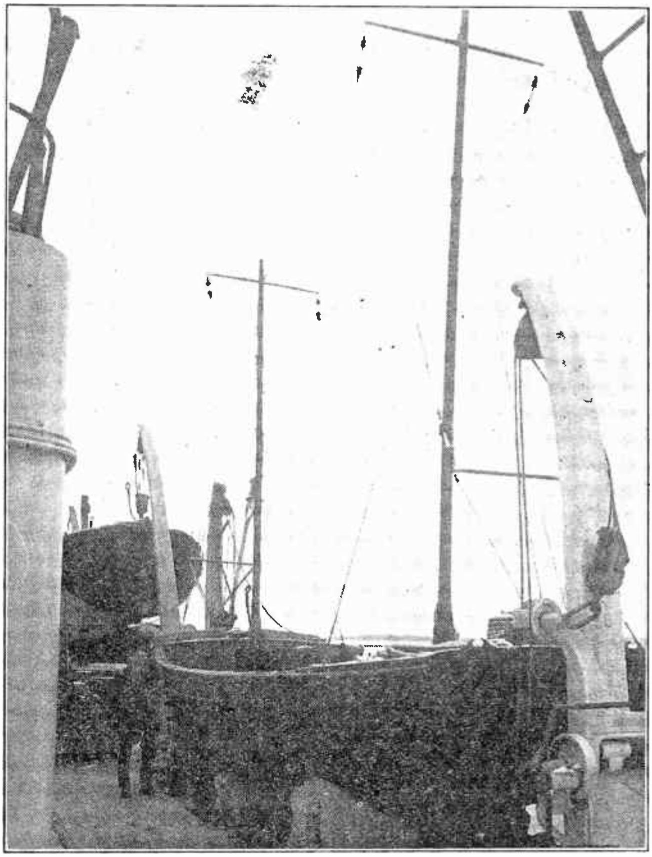


Fig. 507. Motor Boat of the Passenger Vessel Columbus of the North German Lloyd Line.*

*Photograph sent from Berlin to the author by the Telefunken Company especially for publication in this text book.

wheel, which is revolved one step for each motion of the armature. On the code wheel is mounted a spring which completes the electrical circuit with a stationary contact. There are also mounted on the code wheel a series of pins which engage a spring. The individual call of the selector is determined by the position of these pins. If the call does not correspond to the setting of the pins on the code wheel, the latter will drop back.

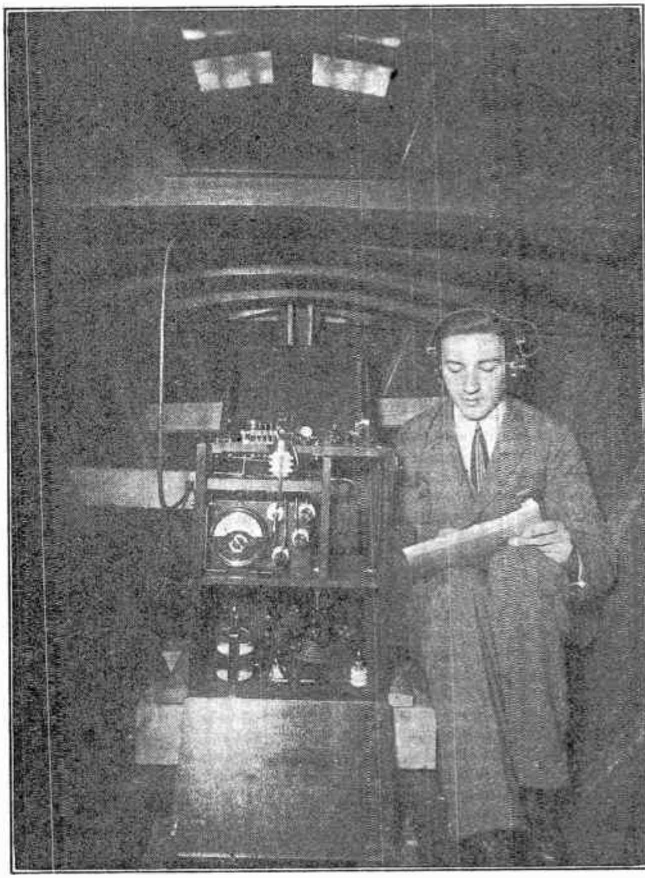


Fig. 508. Telefunken Transmitter Installed in the Motor Boat of the Columbus.*

*Photograph sent from Berlin to the author by the Telefunken Company especially for publication in this text book.

The operation of the D-80610 relay completes the circuit of the *signal lamp* and also of the No. 10-D *bell* which is connected in parallel with the lamp, calling the attention of the operator to the call.

Across the filament of the 215-A vacuum tube is connected a lamp which will light if the filament of the tube is burned out, thus calling the operator's attention to this.

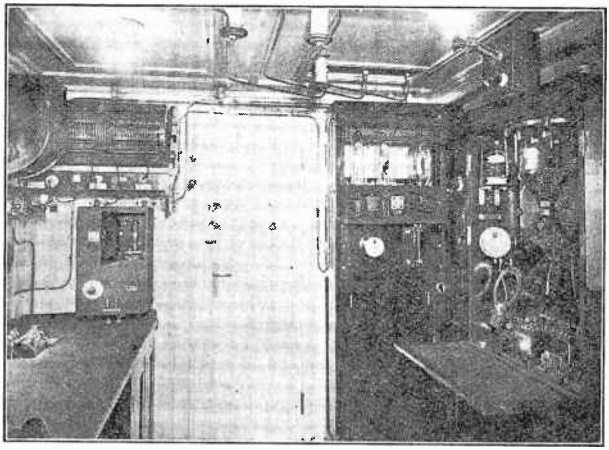


Fig. 509. The Radio Room on the Columbus.*

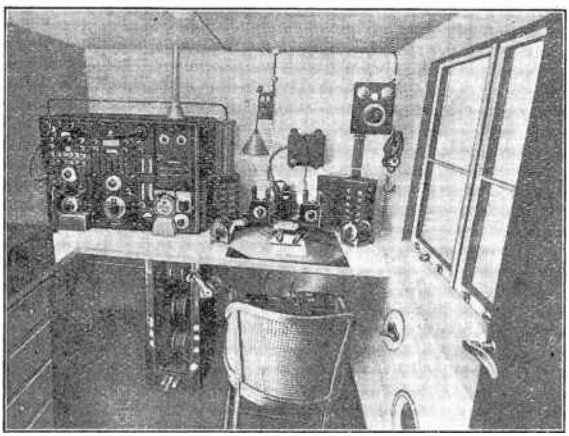


Fig. 510. Radio Cabin of the ZRIII, or Los Angeles.*

*Photograph sent from Berlin to the author by the Telefunken Company especially for publication in this text book.

418. The *Telefunken Company,* of Berlin, Germany, which is a consolidation of several important manufacturing concerns, similar to the Radio Corporation of America, has produced many fine types of radio apparatus. The quenched-spark gap was invented and developed by engineers of this company.

Figures 506 to 512 are photographs of Telefunken in-

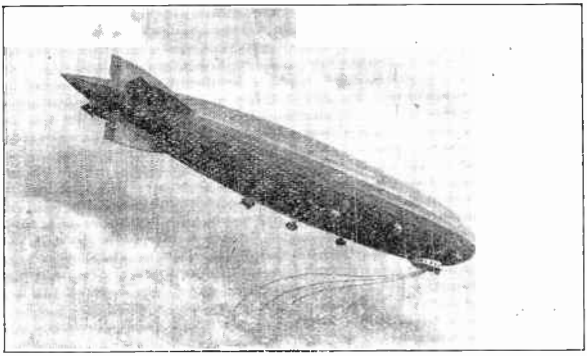


Fig. 511a. The Zeppelin ZRIII, Constructed by the Telefunken Company and Rechristened the Los Angeles, after its purchase by the United States.*

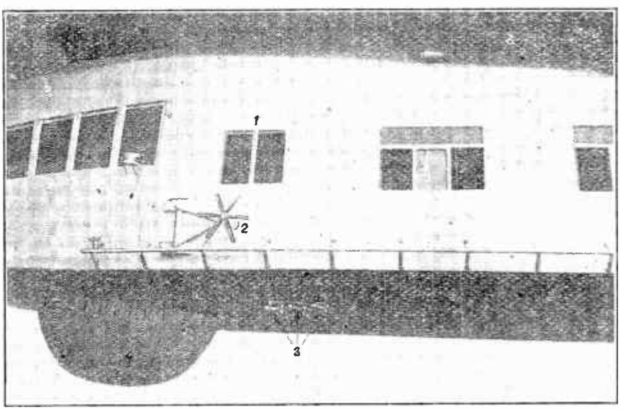


Fig. 511b. A Close-up View of the ZRIII Cabin.*

*Photograph sent from Berlin to the author by the Telefunken Company especially for publication in this text book.

stallations on various German-built craft. The antenna on the motor boat of the Columbus is ingenious in its adaptation of length of wire to the limited length of the boat. This might easily serve as a model for an antenna installation on a pleasure boat. In figure 509, at the lower right, can be seen a receiving apparatus which shows some resemblance to

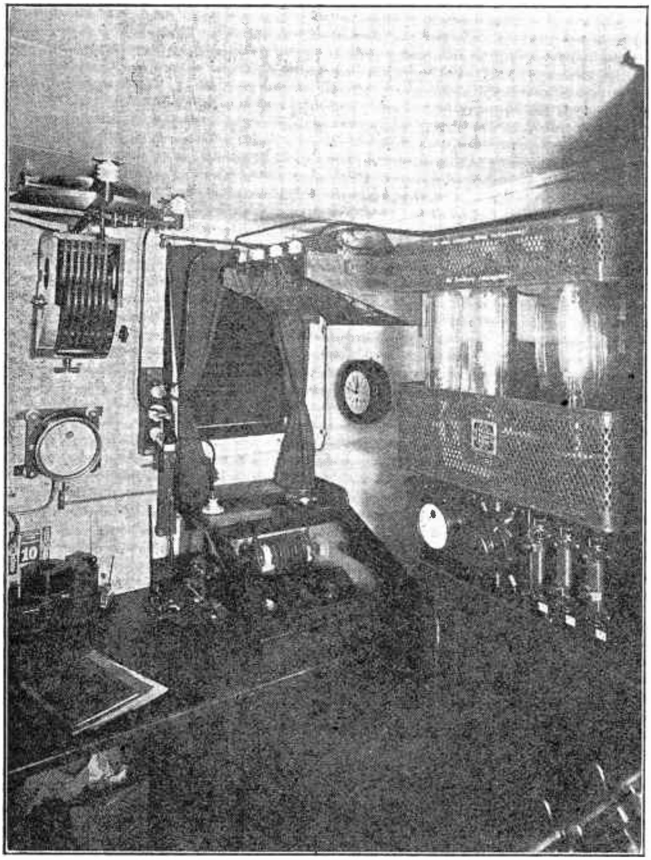


Fig. 512. A Corner in the Radio Room of the Lloyd Liner Sierra Verbana.*

*Photograph sent from Berlin to the author by the Telefunken Company especially for publication in this text book.

the older type of receiver constructed by this concern, with the honey-comb coils mounted on the front of the panel. In figure 512, a quenched-spark gap is shown, enclosed in glass, to be used if desired, and at the upper left corner are the wave-length-changing inductances.

Figure 511a shows the three-wire trailing antenna of the Los Angeles (ZRIII), and in figure 510 the transmitter and receiver may be seen inside the radio cabin, with the three antenna wires on three reels beneath the table. In figure 511b, 1 indicates the radio cabin, 2 is the wind-driven generator, 3 indicates the three weights attached to the three antenna wires, and 4 a sound-proof casement.

419. In connection with some of the older installations, what was called an *anchor gap* was used. This consisted of a spark gap in an insulating ring. This gap was connected in series in the antenna circuit, and served to automatically change from receive to send, without the manipulation of any switches. When sending, the higher powered oscillations jumped to the ground, and transmitting

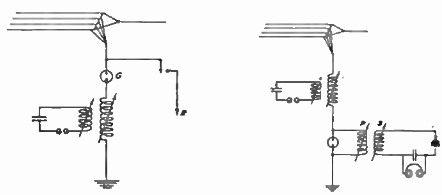


Fig. 513. Anchor Gap. (Bucher.)

was possible; but when receiving, the weaker energy of the received signals could not jump this gap. The disadvantages of this were that it placed the undesirable resistance of the gap in the antenna system, and that it easily became short-circuited by the accumulation of dust which soon became charred from the high potential current. The space between the electrodes was necessarily small, so this was easily filled up.

420. An old variation from the simple receiving circuit, which is useful at sea, is known as the *"stand-by"* arrange-

ment. This is illustrated in figure 514, in fundamental form. The idea is to have provisions made for listening in, or "standing-by" on broad tuning, and for switching to a more sharply tuned circuit when a station is heard.

An *intermediate circuit is also used, sometimes.* This has the advantage of great selectivity, and might be called a "wave selector." It was used in the old days with some of the early types of crystal-detector apparatus, but was found to reduce the volume of the signals, and so was discarded. Used with the more sensitive vacuum-tube receiving sets, with several stages of amplification, it may prove quite practical in copying through interference.

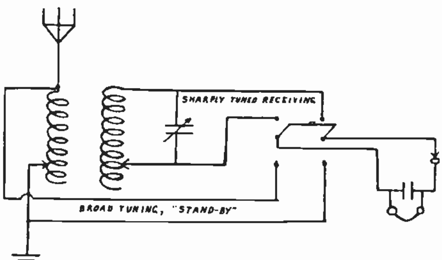


Fig. 514. "Stand-By" Receiving Circuits

Much more elaborate, but somewhat on the same order is the Alexanderson barrage system. This consists of a balanced circuit containing many coils mounted at different angles, and having the effect of producing great selectivity. Two ground connections are used, as in figure 516. This apparatus is used in the U. S. Navy, but not very likely to be seen on any vessels of the merchant marine.

A still different principle in receiving, shown in fundamental form in figure 517, is the Weagent system. This com-

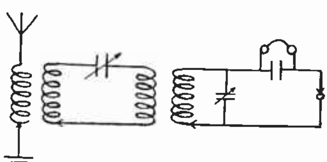


Fig. 515. Receiving Set with Intermediate Circuit.

prises a three-winding coil having two long extensions in opposite directions, as shown, forming practically two loop antennæ, inductively coupled to the secondary of a receiving set.

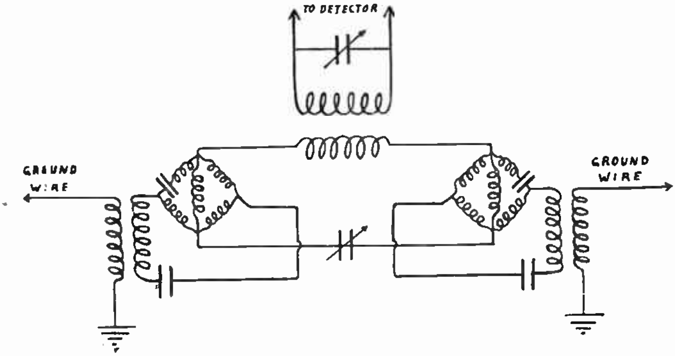


Fig. 516. Alexanderson Barrage Receiving System.

If a beat-note vacuum-tube receiver is not installed on board a ship, for the reception of continuous-wave signals, by far the most common device used for this purpose is a motor-operated interrupter. It may consist of a "tikker,"

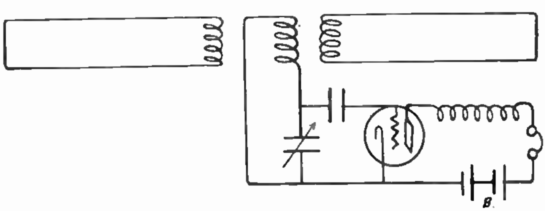


Fig. 517. Weagent Receiving System.

which is a spring contact against a pulley-shaped disc, in which a make and break are made by the vibrating of the spring contact caused by the centrifugal force of rotation of the disc. A device similar to a chopper is sometimes used, the make and break being caused by the insulating wedges on the edge of the disc instead of by the force of rotation. In either case the result is about the same. The chopper interrupter is sometimes called a tikker also. No crystal detector, or other rectifier, is required with these devices. The theory of the operation is as follows: When the contact on the tikker is closed, the high-frequency oscillations in L and C_1 figure 518, charge the telephone condenser, C_2; and when the contact on the tikker is opened, this charge in C_2 is released through the telephones. Each one of these discharges makes a click in the telephones, so the pitch of the note heard depends solely upon the speed of rotation of the disc. The sound is buzzing in character.

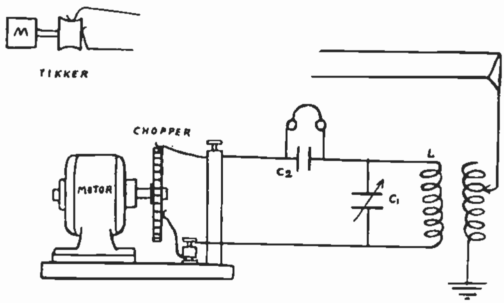


Fig. 518. Tikker Method of Receiving Continuous Waves.

A device somewhat similar is the Goldschmidt tone wheel. This consists of a smooth, wide disc rotated by a motor, and having brushes similar to those used on motors and generators. These are controlled by springs which cause them to alternately touch the wheel and be released from it. With this the telephone condenser is omitted and, if the wheel runs at the same frequency as that of the impressed current, nothing is heard in the telephones, but if the wheel runs at a different frequency, it impresses different parts of the alternations upon the telephones, and the effect is similar to a *beat note.*

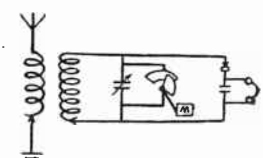


Fig. 519. Detuning Method of Receiving Continuous Waves.

Figure 519 shows the detuning method of receiving continuous waves. This employs the usual crystal detector, and simply has a condenser added, in shunt, to the usual tuning condenser, with the rotating plates turned on a motor shaft. The effect of this is to periodically tune the circuit into and out of resonance with the incoming signals, and this variation makes the signals audible in the telephones. The pitch depends upon the speed of the motor.

421. Closely connected with marine work is the underground system of radio communication invented and developed by Dr. J. Harris Rogers, of Hyattsville, Md., and which he gave to his country during the World War. At first, its value was considered purely military, but recently it has been predicted that this may provide a means for cutting down at least a part of the interference due to so many signals being sent by the overhead route. There is also the advantage of avoiding fading due to the ionization of the sun's rays as this cannot affect the signals if sent underground. This system, which was patented in 1919, consists of the use of insulated wire antennæ, buried in the ground, or installed on submarines, or below the water level on ships. Sometimes the submarine antennæ are placed inside the shell instead of over the deck as shown in figure 520, with about the same results. The buried antennæ, on land, used for communicating under water with ships at sea, are placed at perma-

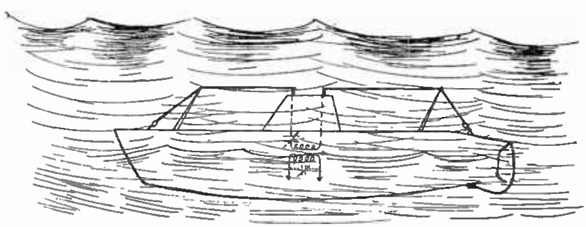


Fig. 520. Submarine Equipped for Underwater Radio Communication.

nent water level, in the plane of signals from certain given stations, or points prearranged for communication. While it is possible to employ a single wire, Dr. Rogers has secured the best results by the use of two parallel wires of different length. The longer the wires, the longer the wave length to which they will respond. This type of antenna is highly directional. Therefore, when signals are received from the station for which the antenna is "planted," it is exceedingly efficient, but as it is mechanically immovable, it can not be used with equal success for receiving from stations not in a corresponding plane. For this reason, Dr. Rogers has at his station in Hyattsville, Md., a number of buried antennæ, of various lengths, and at different angles, which he can select for use in his laboratory by means of switches, thereby having means for picking up signals from every direction. Dr. Rogers believes that the energy passing into the ground by way of the ground connection of a transmitter travels farther and with greater force than the electromagnetic waves radiated via the overhead antenna, on account of the ground being a conductor and the air an insulator. In tests made during the spring of 1925, Dr. Rogers was successful in reaching Europe on extremely short wave lengths with a comparatively low powered vacuum-tube transmitter.

Messages sent out under water, from a submarine, do not set up electromagnetic waves above the water, to any great extent if at all, so that messages transmitted in this manner are not picked up by stations depending on overhead antennæ. A high degree of secrecy is possible. Likewise, messages transmitted from airplanes are not picked up by

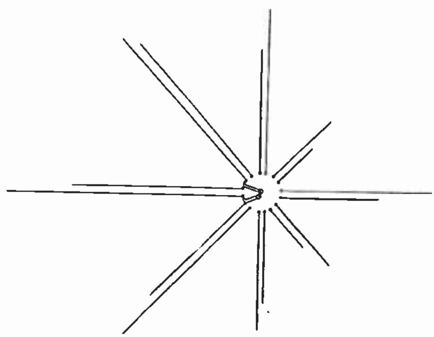


Fig. 521. Plan of the Buried Antennæ at Hyattsville.

the underground system, which seems to indicate, in the opinion of Dr. Rogers, that the waves emitted from the plane do not penetrate the ground.

Although Dr. Rogers has specialized on receiving with this system, he has used it successfully for transmitting also, having a 5-K. W. arc transmitter installed at his station in Hyattsville.

The writer has heard European stations very clearly over Dr. Rogers' underground antennæ. An ordinary regenerative vacuum-tube receiver was used, connected as shown in figure 522. By turning the switches connected to the different buried wires, shown in figure 521, he could pick out different stations. These wires are enclosed in pipes of different materials, which were tried experimentally, and Dr. Rogers stated that an iron pipe gave the best results. He also explained that the wires must be of different length or the system would not work. He has experimented with wires as long as 16,000 feet, but has found 4,000 feet the greatest length with which results are good. Past that signals become weaker.*

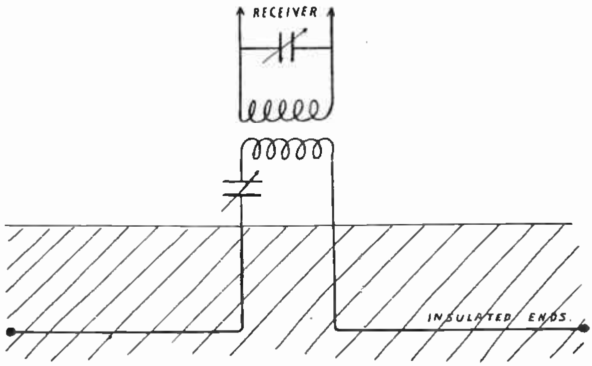


Fig. 522. Dr. Rogers' Method of Connecting Underground Antennæ to Receiving Apparatus.

422. In some of the high-powered transoceanic radio stations, and on some of the larger vessels, there are *automatic* methods of transmitting and receiving. These are not designed to do away with hand sending, or the regular duties of the practical radio operator. They are rather intended to assist him in handling a vast amount of work with greater speed and fewer mistakes than are possible by the hand sending method. The automatic transmitting is accomplished by use of a perforated tape, and the receiving by means of either a photographing or inking register, which records the signals on tape. Great care must be taken in punching the code on the tape, that the keys of the punching machine are pressed slowly and with even pressure. When nicely made a piece of perforated tape is easily read at sight, by the relation of the upper and lower dots to each other. When two dots are directly over each other a dot is formed at the receiving station, and when the dots are oblique, a dash is formed. Sending with this perforated tape is done by means of a wheel, about six inches in diameter, which carries small pins. These pins slip through the holes

*See *Radio News*, June, 1926, for account of Dr. Rogers' 40-meter reception on superheterodyne, with antenna composed of copper discs on copper rod sunk in water hole.

in the paper tape, thus making and breaking a contact which operates a magnetic relay key. The tape may be "unwound" at a rate that will cause the characters to be transmitted at a terrific speed, as compared to the usual methods, say from 50 to 100 words per minute. This means a shorter time for actual occupation of the "ether channel," although the time consumed in preparing the tape was greater than that re-

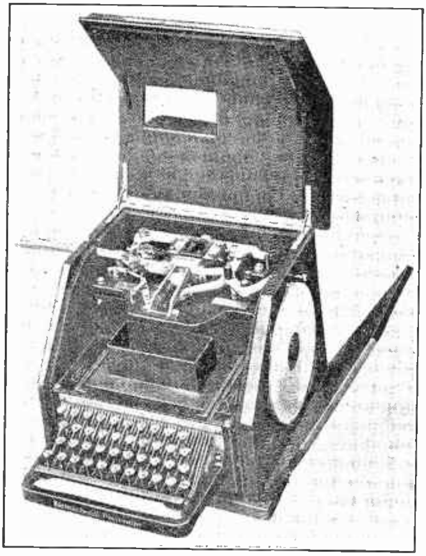


Fig. 523. Tape-Punching Machine.

quired had the message been transmitted by hand. At this high speed, a fair degree of secrecy is obtained, as well as economy, in sending time, for only those can copy it who have appropriate recording apparatus for receiving. This may be either a photographic outfit, or an electromagnetic relay operating a stylus. The photographic recorder is shown in figure 525. This is manufactured by the General Electric Company. Quoting from Admiral Robison: "A rather high pitched beat note is used—namely, about 2,000

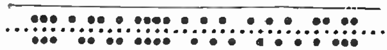


Fig. 524a. Piece of Code Tape Produced by the Machine Shown in Fig. 523. This Spells the Word "School."

cycles, and the recorder is specially tuned to this frequency. The incoming audio currents of this frequency operate a vibrating reed, which in turn vibrates a small mirror which deflects, slightly, a beam of light. This light beam is thrown onto a moving photographic paper tape. Thus, a set of telegraphic signals will produce corresponding bands of light upon the moving paper tape. The tape is driven by a motor, and is passed successively through developing, fixing, washing and drying tanks. The tape then emerges from the machine in a dry condition, ready for reading. The recorder now being used at the naval station, Bar Harbor, has a maximum speed of 200 words per minute, and can accommodate 10,000 feet of tape at one time."

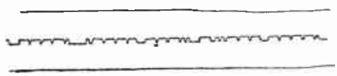


Fig. 524b. Inked Register of Automatic Receiving.

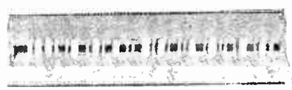


Fig. 524c. Photograph of Automatically Transmitted Word "Particular."

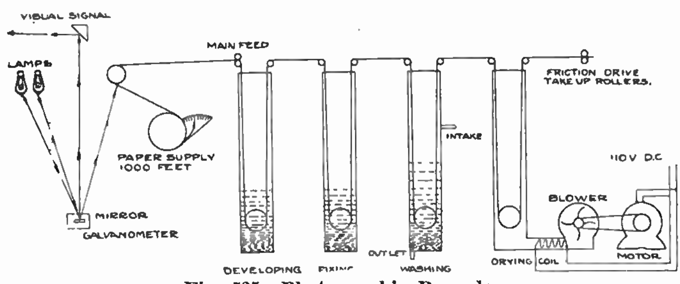


Fig. 525. Photographic Recorder.
(Robison.)

In the high-powered transoceanic radio stations copying, when not of too high speed and when not accomplished by automatic mechanism, is usually done on the typewriter. Operators copy automatic-tape-transmitted signals on the typewriter at from thirty to thirty-five words per minute.

423. Radio control of moving bodies, such as ships, airplanes, bomb planters, etc., may reasonably be expected to rank among the most important radio activities in case of further wars. The idea has been also applied to several

amusing toys and spectacular theatrical features. Possibly it may be found to have some practical usefulness in the routine work of the commercial radio operator of the future.

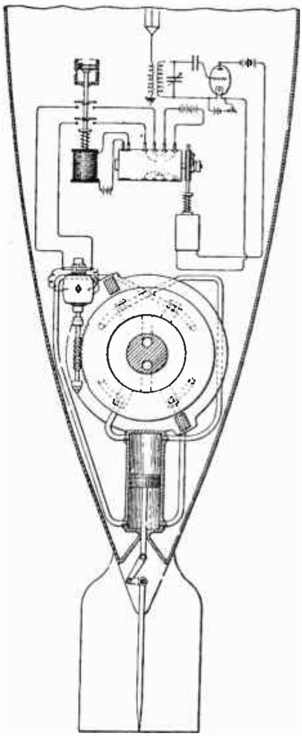


Fig. 526. John Hays Hammond's "System for Controlling Moving Bodies from a Distance."

Numerous patents covering various phases of the development of radiodynamic control have been granted to John Hayes Hammond, Jr. Figure 526 is from patent paper 1,473,149, for a "System for controlling moving bodies from a distance," granted November 6, 1923. For causing the rudder to move to the right or left, or for steering the body in which the apparatus is installed, a crank arm is secured to the rudder and joins a connecting link which has pivoted engagement with a piston rod. The piston rod projects through the end of a cylinder in which the piston is adapted to reciprocate and a flow of liquid, usually compressed air, is controlled and fed into certain pipes automatically selected by the mechanism. For the purpose of admitting the compressed air to the cylinder and automatically exhausting the same to maintain the vessel upon a predetermined course, a control system consisting of a gyroscope having a shaft fixed in space by a stabilizer is used. The shaft is provided with a pair of passages for this exhaust, and as the mechanism is turned, the compressed air escapes through a selected port according to the position of the passages in the shaft. The position of the gyroscope depends upon the position of a motor operated gear, which in turn is controlled by an electromagnetic relay, which is operated by the energy picked up by the antenna. The receiving apparatus is tuned to the wave length of the controlling transmitter, and control exercised by stopping the transmission after sending for a predetermined period of time, by changing the frequency, or the strength of the signals.

Figure 527 is from patent 1,513,108, granted October 28, 1924. This consists of a receiving antenna and vacuum-tube receiving circuit, a directional loop antenna, with a vacuum tube as shown in the drawing, or two tubes having their filaments separately lighted. Two selenium cells are used for making the apparatus respond to light beams. When a light, such as from the search-light of a ship, is thrown on the selenium cells, the resistance in the battery circuits in which they are connected is varied accordingly, and if the light does not strike them squarely, the apparatus will turn, to place the cells so that each receives the same amount of light, and the body will move towards this light-wave interference. In the case of a torpedo, a search-light of an enemy ship would attract it, and it would destroy that ship. The body may also be attracted, or repelled, or turned to the right or the left, by means of electromagnetic energy radiated from a controlling radio transmitting station.

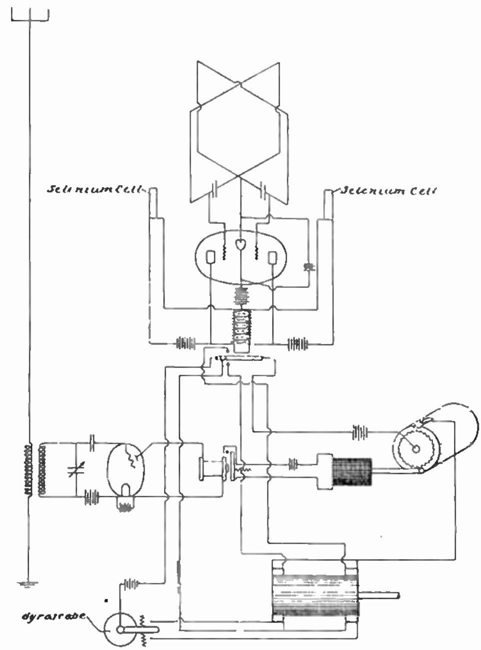


Fig. 527. Hammond System for Controlling Moving Bodies, by Causing Them to Move Towards or Away from the Disturbing Energy.

(Copies of the above patents, containing detailed descriptions, can be obtained at the Patent Office, Washington, D. C., for 10 cents each.)

CHAPTER 38

Meters and Measurements

C. G. S. System of Absolute Units—Table of Units—Galvanometers—D'Arsenval Voltmeters and Ammeters — Multiplier — Shunt Ammeter — Plunger Ammeter—Dynamo Meters—Wattmeters—A. C. Vane Meters — Hot-Wire Meters—Thermal-Junction Meters—Current-Transformer Meter—Frequency Meters—Power-Factor Meters — Three-Phase Power-Factor Meter — Kilowatthour Meter—Mercury Ampere-hour Meter—Wheatstone Bridge and Ohmmeters—Slide-Wire Bridge—Megger—Measurements of Resistance—Wavemeters—Uses of Wavemeters—Circuit-Driver—Decremeter—Straight-Line Condenser—LC Measurements—LC Table—Resonance Curve—Bridge Measurements of Capacity and Inductance—Inductance Tables—Antennna-Resistance Measurements—Antenna Nodes—Harmonics—Measurements of Constants of Vacuum Tubes—Audibility Meter—Care of Meters.

424. In order to understand the operation and applications of the various types of meters to electrical measurements one must first know something about the different properties or quantities to be measured. The measurement of a quantity consists of the comparison of that unknown quantity with a known unit of the same kind of quantity. Measurements may be classified as direct and indirect. In direct measurements the comparison is made directly. For instance, as with a yard stick, or quart measure. In indirect measurements the number sought is determined by use of a formula, proving the relationship of two or more properties or quantities. For instance,

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

Quoting from F. Malcolm Farmer, in his *Electrical Measurements in Practice:*

"The fundamental electrical units are based on the c. g. s. system of absolute units. This system is founded on the centimeter, gram and second units which have a perfectly definite significance. There are two c. g. s. systems of electrical units, the electromagnetic and the electrostatic. The electromagnetic system is derived from the unit magnetic pole defined as a pole of such strength that it repels a similar pole at a distance of one centimeter with a force of one dyne. The electrostatic system is but little used and all electrical measurements are based on the electromagnetic system. The various units in these two systems have never been officially named, but some writers prefix the name of the practical unit with 'ab' or 'abs,' and 'stat' when referring to the corresponding c. g. s. unit. Thus 'absohm' refers to the absolute unit of resistance in the electromagnetic system and "statohm" refers to the corresponding unit in the electrostatic system. The fundamental c. g. s. units are difficult to represent and cannot, therefore, be used directly in ordinary electrical measurements. It was recognized early in the development of the art that convenient standards were necessary. Consequently, a system of practical units was established which was derived from the c. g. s. electromagnetic units and which could be represented by definite, concrete and reproducable standards."

The accompanying table shows the relation between the practical units and the absolute units in both the electromagnetic and electrostatic system.

"The precision obtainable in an electrical measurement depends upon the various factors which enter into the determination; among these are the correctness of the principle employed and the method used, accuracy of standards, number and magnitude of possible errors, correctness of calculations and so forth. In many precision instruments, a precision of 1 part in 1,000,000 in certain classes of measurements is regularly attained. In commercial measurements, the cost of such a high degree of precision is not justified. The limits, however, are being gradually raised as the art develops and greater refinements are introduced."

The exact value of the *charge of one electron* is equal to 4.774×10^{-10} electrostatic units.

425. The development of the various meters used today in electrical and radio work has played an important part in the history of these arts. Historically, the first meter was without doubt the *galvanometer.* Since the invention of the galvanometer, measuring instruments have been developed for measuring electricity from every conceivable angle. There are direct-current meters, and alternating-current meters, for measuring the quantity of electricity flowing in d. c. and a. c. circuits, for measuring the pressure at which this electricity circulates through the circuit, for measuring the power developed by the combination of this quantity and pressure; there are different types of hour meters which indicate the amount of power expended, or the current used, at the rate of a predetermined quantity per hour; there are meters for measuring the resistance of a circuit, or the efficiency of an insulating material; and meters for indicat-

TABLE OF UNITS

(From Standard Handbook for Electrical Engineers, 4th edition)

Quantity	Symbol	Practical Unit	Absolute C. G. S. Unit	
			Electromagnetic	Electrostatic
Electromotive force	E	volt $=10^8$ abvolts	abvolt $=10^{-8}$ volt	statvolt $=300$ volts
Resistance	R	ohm $=10^9$ absohms	absohm $=10^{-9}$ ohm	statohm $=9\times10^{11}$ ohms
Current	I	ampere $=10^{-1}$ absampere	absampere $=10$ amperes	statampere $=3.333\times10^{-10}$ ampere
Quantity	Q	coulomb $=10^{-1}$ abcoulomb	abcoulomb $=10$ coulombs	statcoulomb $=3.333\times10^{-10}$ coulomb
Capacitance	C	farad $=10^{-9}$ abfarad	abfarad $=10^9$ farads	statfarad $=1.111\times10^{-12}$ farad
Inductance	L	henry $=10^9$ abhenrys	abhenry $=10^{-9}$ henry	stathenry $=9\times10^{11}$ henrys
Energy	W	joule $=10^7$ abjoules (ergs)	abjoule (erg) $=10^{-7}$ joule	statjoule (erg) $=10^{-7}$ joule
Power	P	watt $=10^7$ abwatts $\frac{\text{(ergs)}}{\text{(sec.)}}$	abwatt $\frac{\text{(ergs)}}{\text{(sec.)}}=10^{-7}$ watt	statwatt $\frac{\text{(ergs)}}{\text{(sec.)}}=10^{-7}$ watt

ing the frequency of an alternating current; and wavemeters for measuring the wave length of radiated waves. There are meters to be fastened on switchboards, and portable meters in carrying cases. Speaking generally, meters may be classified into those operating on the principles of magnetism and those known as hot-wire instruments, which are operated by the expansion of a resistance wire under the influence of the heat generated by the current.

Any instrument constructed for measuring electricity in small quantities may be called a *galvanometer,* but a galvanometer is generally understood to be an electromagnetic device for indicating current in a circuit. The simplest forms do little more than this. The most elementary type of galvanometer is that shown in figure 528. This is known as a tangent galvanometer. It consists of a coil of very fine wire supported in a vertical position and having inside of it a small compass dial equipped with a permanently magnetized needle. When the coil is not connected in a circuit, this needle will point north and south, drawn by the magnetic poles of the earth. If the coil is placed in a position exactly parallel to this needle, when it is pointing north and south, and the coil connected in a circuit, the degree of deflection of the needle from its original position will indicate the intensity of the current flowing in the circuit. By calibrating this apparatus properly it can be used for indicating small quantities of current, in more or less accurate measurements. For instance, if the needle deflects 45° for one ampere of current flowing through the coil, other quantities of current will cause deflections which can be used for determining the amount of current by comparison. If the needle is deflected 90° there must be two amperes in the circuit, etc.; 90° is the limit of usefulness of this device.

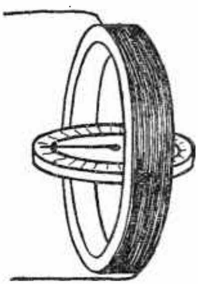


Fig. 528. Tangent Galvanometer.

In laboratory work, this reading of degrees of the arc is not used so much as the tangent of the degree, which indicates the distance from the zero position to the position taken by the needle. See page 111 for table of tangents.

EXAMPLE.

A tangent galvanometer needle deflects 17° when the coil is connected in series with a Leclanche cell, and 42° when connected with a Fuller Bichromate cell. What is the relative strength of the current in the first case to that in the second?

Answer. Deflection 1 = 17° and D_1 tan = 0.3
Deflection 2 = 42° and D_2 tan = 0.9

$$I = \frac{I_2 \times \tan D_1}{\tan D_2} = \frac{I_2 \times 0.3}{0.9} = \frac{1}{3}$$

or the current obtained from the Leclanche cell was one-third as strong as that from the bichromate cell, or the latter was three times as strong as the former.

Sometimes the coil is made up of several separate turns having leads brought out to separate binding posts, so that the sections can be connected in series or used singly as desired. The fewer turns used for a given diameter of the coil, the greater the sensitiveness of the instrument; also the greater the diameter of the coil the greater the sensitivity.

Some very sensitive galvanometers are constructed with a small mirror enclosed. In order to obtain a reading from this, the room is darkened and a light reflected on this mirror. A graduated scale is arranged so that the delicately suspended working part of the meter can throw a ray of light along this scale.

Another type of galvanometer is shown in figure 529. In this the indicating pointer is attached to a coil of wire, through which the current passes, and inside of which is an iron core. This is mechanically supported so that it is free to turn between the ends of a strong horseshoe magnet. When current passes through the coil, the magnetic lines of force formed around the coil cause it to turn with a tendency to enclose as many of the lines of force of the magnet as possible. It is prevented from rotating by the twisting of the wire which suspends the loop. By planning the weight of the wire used, the number of turns in the coil and the amount of resistance used, this device can be used for measuring small quantities of current. This principle is the basis of many makes of commercial ammeters and voltmeters. They are known as D'Arsenval meters.

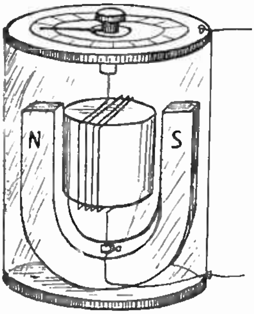


Fig. 529. Laboratory Type D'Arsenval Galvanometer.

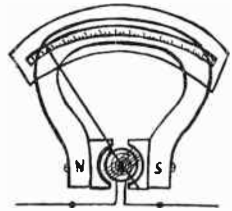


Fig. 530. D'Arsenval Type of Ammeter.

426. The principal difference between the direct-current voltmeter and ammeter is one of resistance. The *ammeter is connected in series* in the circuit, and as the current must pass through the winding, this is made of a few turns of heavy wire to have a low resistance. By making the coil of many more turns of fine wire and connecting it across the circuit, with an additional resistance in series to protect the coil, we have a means of measuring the electrical pressure of a circuit. Referring to the connection of the *voltmeter in shunt* in the circuit, Professor Rupert Stanley says: "One does not measure the steam pressure going to an engine by diverting a lot of steam and bringing it to the steam gauge; if this were done the pressure in the engine cylinders

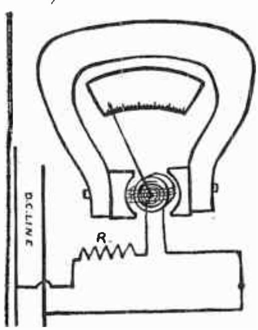


Fig. 531a. D'Arsenval Voltmeter.

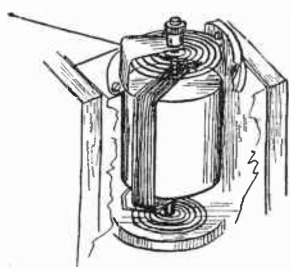


Fig. 531b. Working Parts of D'Arsenval Meter.

would be seriously reduced. A small pipe leads a small quantity of the steam to the steam gauge, and for similar reason a voltmeter has a high resistance, so that very little current will be used in it when measuring the voltage; the wires connecting the voltmeter to the points desired can be therefore of small diameter."

The voltmeter will not necessarily be burned out by connecting it in series with the line, but by this method its high resistance is removed from the path of the current.

The external resistance is usually called a *multiplier,* on account of its increasing the range of the instrument, by making it possible to use the meter on voltages which would

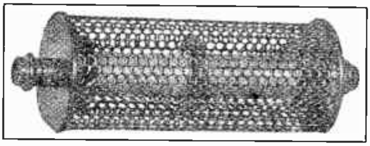


Fig. 531c. Roller-Smith Multiplier.

otherwise burn it out. In order to obtain reliable readings, it is necessary to have the meter and multiplier calibrated together, and the added resistance should be a multiple of the resistance of the movable coil of the meter. The reading is then multiplied by a given constant, as 3, 5, 10, etc. For instance, in a table showing the range of voltmeters made by a prominent concern an instrument is catalogued as having a range from 0 to 3 volts without the multiplier, and up to 150 volts with the multiplier. Another one has a range of 350 volts without the multiplier and up to 3,500 with it. Sometimes the multipliers are made with taps, giving constants to be used for obtaining intermediate-voltage readings. When the meter is to be used on the same range all the time, the multiplier may be included in the same case with the working coil, or mounted externally as a permanent part of the installation, and the voltmeter dial is then calibrated to give readings in which the multiplier constant has been used. The resistance coil, when mounted externally, is enclosed in a perforated rectangular box, or cylinder. The potential coil multiplier can be seen in figure 537, built into the case of a wattmeter. This consists of many turns of fine wire wrapped over shellacked fiber.

In commercial types of ammeters and voltmeters, there is a flat spiral spring connected with the revolving coil, to give added tension and control of the pointer. In some cases the current passes through this spring, and in others it is purely mechanical and not connected in the circuit electrically. The instruments are furnished with dials giving readings based on the metric system.

427. It is customary to build *ammeters* with *calibrated shunts.* With the ammeter connected directly in series in a circuit which carries large quantities of current, it is nec-

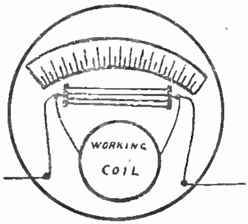


Fig. 532. Ammeter with Calibrated Shunt.

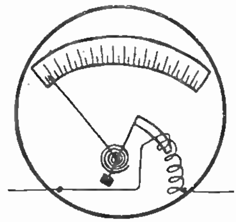


Fig. 533. Plunger-Type Magnetic Meter.

essary to have an extremely large coil in order to obtain the magnetic field required for measuring purposes, and this is heavy and bulky. With the calibrated shunt, however, the ammeter proper passes only a small proportion of the current, the rest passing around the working part of the meter by way of the shunt, thus protecting the working coil from burning out from the large amount of current and making it possible to obtain accurate readings of the actual quantity of current flowing without the use of the larger coil. This is accomplished by calibrating the instrument in such a way that the *readings* given on the dial for a measurement of the portion of current, which passes through it by way of the divided circuit, will be the same readings that would have been given in case the larger and heavier instrument had been used. It is usual to employ a shunted conductor which passes nine-tenths of the current, while only one-tenth passes through the working coil. For instance, if a large-coil standard ammeter indicates exactly ten amperes flowing in a circuit, the smaller coil can be constructed to pass exactly one ampere, with a conductor which passes nine amperes shunted around it. Normally the reading of this coil would be one ampere, but as ten amperes are actually flowing in the circuit when the small coil gives a reading of one ampere, the dial is arranged to give a reading of *ten* amperes.

428. For measuring direct current in quantity or pressure, small meters are sometimes made, as shown in figure 533. There is a pointer attached to a hook-shaped strip of iron,

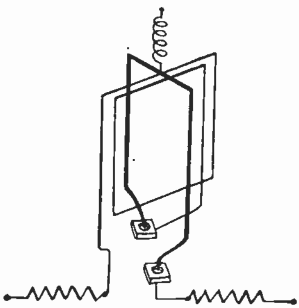


Fig. 534. Dynamotor Voltmeter.

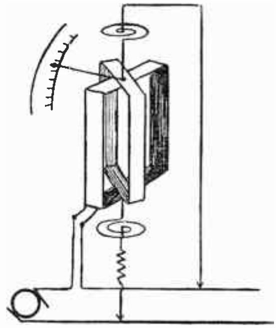


Fig. 535. Fundamental Principle of Sieman's Dynamotor Wattmeter.

and this plunger is drawn into the solenoid by the magnetic force of the current through the solenoid. This is known as the moving-iron type of instrument. It gives fairly accurate readings, and may be calibrated to read in amperes or volts. Its principal use is in connection with batteries.

429. Another variation in the form of magnetic measuring instruments is called the *dynamotor*. This consists of two coils of wire, placed one within the other, and at right angles to each other, one stationary and the other movable. A strong spring is attached for added tension, or torque. This instrument may be used for measuring amperes, but is more satisfactory as a voltmeter. Wattmeters are also operated on this principle. When constructed as a voltmeter, the coils are made of many turns of very fine wire, having a high resistance. It is supplied with additional resistance coils, and connected in shunt to the circuit. The coils of the voltmeter are in series with each other. The stationary coil and movable coil set up magnetic fields at right angles to each other, and the torque produced by these fields is a measure of the pressure of the circuit, when calibrated to give readings in volts.

430. The *dynamotor wattmeter* is practically a small motor, calibrated to give readings in watts. The meters shown in figures 535 and 536 can be used on either direct

or alternating current. For direct-current circuits the power is usually determined from the product of the current and voltage. Alternating-current power is most accurately measured with wattmeters. No iron cores or permanent magnets are used in these meters, the fields depending entirely upon the current passing through the coils, and the power indicated being the tension created between the current coil and potential coil.

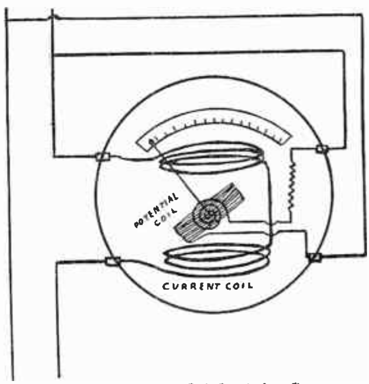


Fig. 536. General Electric Company's "Electrodynamometer."

In figure 537, the base below the coils is hollow, and contains two chambers in which are two balanced vanes. This is in effect a small dash-pot.

431. When a direct-current ammeter is placed in an alternating-current circuit, the ammeter pointer will either stand at zero or give a blurred appearance. Several types of meters are made for use on alternating current. Others may be used on either direct or alternating. These meters will give a reading in the same direction regardless of the direction of the current; and the force exerted on the mov-

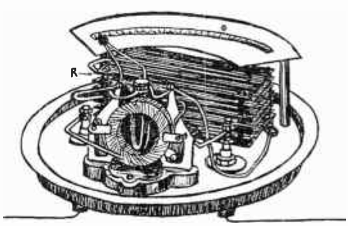


Fig. 537. Weston Wattmeter.

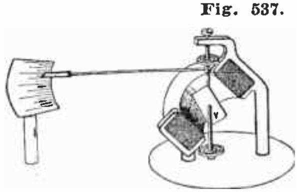


Fig. 538. Cross-Section View of Inclined-Coil Ammeter, A. C. or D. C.

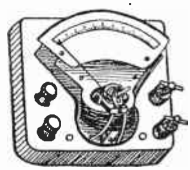


Fig. 539. Thompson Inclined-Coil Wattmeter.

ing part is always equal to the square of the current passing through the instrument. In the case of alternating current this is the average of the squares of the various values during each cycle.

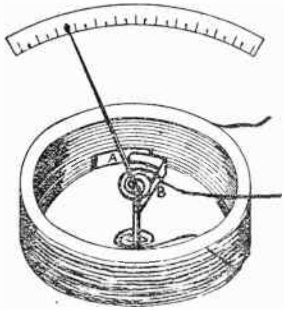


Fig. 540 Magnetic-Vane Meter.

A different type of magnetically operated meter from those described in the preceding paragraphs is the moving-vane type. This may have an inclined coil or not. In the inclined-coil type, a stationary coil is mounted at an angle of 45 degrees. A vertical shaft passes through the center of this coil, which has mounted upon it a soft-iron "vane." The vane turns under the influence of the magentic lines of force surrounding the coil, with a tendency to find the position in which its plane would be parallel to the flux of the coil. This turning carries the vertical shaft and attached pointer around at the same time. The device may be constructed for an ammeter or a voltmeter. By substituting a second movable coil, in place of the vane, we have an inclined-coil wattmeter, which operates on the same magnetic principle.

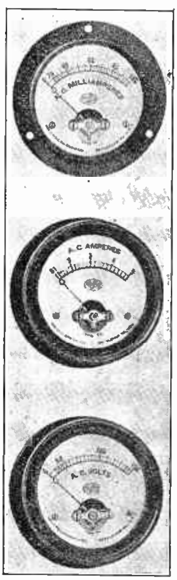


Fig. 541a. Roller-Smith A. C. Meters, Type TA, Designed for Radio Work.

A magnetic vane meter in which the coil is not inclined is shown in figure 540. In this, when current flows through the coil the thin strip of soft iron, A, becomes magnetized, as does also the movable vane, B. These two soft-iron vanes have the same magnetic polarity, and therefore repel each other in proportion to the strength of the current producing the magnetism. This type of meter is especially adapted for use on low-frequency alternating current.

432. In many cases delicate measuring instruments are damaged, or deflected from their true reading, by the influence of external magnetism. This may be terrestrial, or the field of nearby permanent magnets. To overcome this, they are sometimes made with two movable coils placed in two separate

magnetic fields of opposite polarity. The effect of the magnetic pull of these opposite poles tends to neutralize any external magnetic influence. Such meters are known as *astatic* instruments.

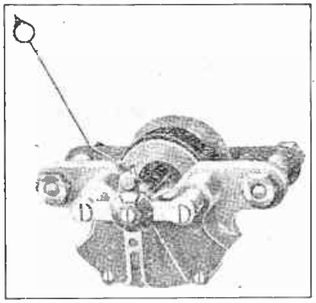


Fig. 541b. Working parts of Roller-Smith A. C. Meters.

433. Measuring instruments are constructed making use of several vanes, as in figure 543. These may be two plates, or vanes, fastened in a stationary position, with one movable vane, or there may be several vanes, arranged alternately, so that they do not touch each other, quite similar in appearance to a variable condenser. The stationary portion is connected to one side of the circuit and the movable one to the other. According to the

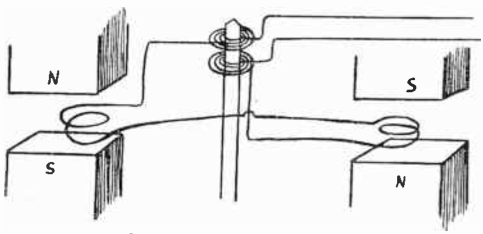


Fig. 542. Fundamental Principle of Astatic Measuring Instruments.

strength of the current, the movable plate or plates will be drawn within the magnetic flux surrounding the fixed plates. The movable plate is provided with the proper tension by means of a spring which draws it back into position as the strength of the current is reduced. Electrostatic instruments are most frequently seen employed as alternating-current voltmeters.

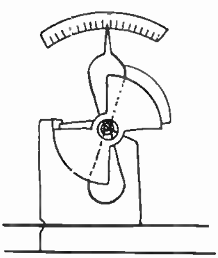


Fig. 543. Moving-Vane Electrostatic Voltmeter.

The type of electrostatic voltmeter illustrated in figure 544 is essentially a high-voltage device. Quoting from F. Farmer, "When potential is applied at A A′, the hollow cylinders C C′ become charged by induction and opposite polarity to A A′ respectively. The resultant attraction produces deflection because of the shape of the fixed plates P P′. The condensers K K′ are each formed by two flat plates and are connected in series with A A′ to increase the range, but for lower ranges these condensers are short-circuited so that ranges of 30,000, 60,000 and 100,000 volts are available in the same instrument and on one scale. *The elements are entirely*

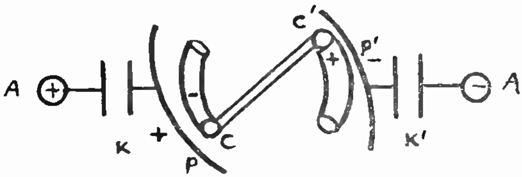


Fig. 544. Westinghouse Electrostatic Voltmeter.

immersed in oil, which permits for high voltages, a relatively compact construction. The oil increases the torque, because it has greater specific inductive capacity than air and this increases the electrostatic charges. It also makes the instrument more nearly dead beat. The principal advantage of electrostatic voltmeters is that they absorb practically no power. The current required is the charging current to the instrument acting as a condenser and that is extremely small. This feature becomes important at high voltages because direct measurement with any of the electromagnetic instruments, even though the current may be only a few milliamperes, requires power which becomes inconveniently large at the very high voltages."

The practical apparatus is, of course, equipped with a pointer and dial.

434. In alternating-current circuits, especially of high frequency, *hot-wire* measuring instruments are used more than those based on the electromagnetic principle. These may depend solely upon the expansion of a wire of calibrated

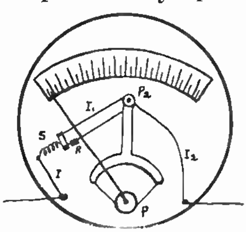


Fig. 545. Rocker-Arm Type of Hot-Wire Ammeter.

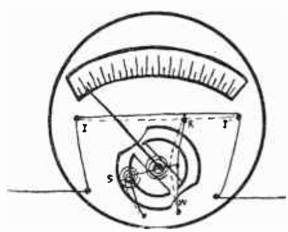


Fig. 546. Hot-Wire Ammeter.

resistance, or a thermo-junction may be used. A common type of hot-wire ammeter is illustrated in figure 545. A pointer is attached to a rocking arm which is free to move to the right or left, and which carries a silk thread having several turns wound around a pulley, P. The current passes through conductors I, I_1 and I_2. The end of the wire I_1 is hooked around the post P_2. An insulator, R, prevents the current from passing around this loop, and a spring, S, keeps the conductor at the proper tension. The mechanical principle is obvious. Conductor I_1 has a high resistance and becomes hot as the current passes through it. As the heat causes this wire to expand, the wire lengthens and turns the post P_2, carrying the rocker-arm around with it. The arm moves toward the left, which turns the pulley and causes the pointer to move across the dial from left to right.

The hot-wire ammeter shown in figure 546 is slightly different, but is operated by the heat generated as the current passes through the conductor from I to I′ An insulator, usually a glass bead, is located at R, to prevent current from passing into the mechanical part of the instrument. As the heated conductor expands, it must move downward, on

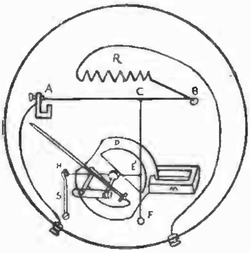


Fig. 547. Hot-Wire Voltmeter Manufactured by Hartmann & Braun Co.

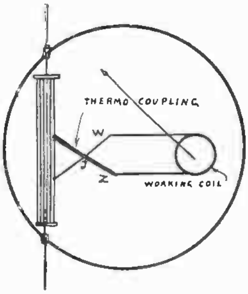


Fig. 548. Thermo-Coupled Radio-Frequency Ammeter.

account of the tension placed upon it by the wire W, and as this takes place, the wire W is drawn to the left by the tension placed upon it by a silk thread wound around the post S, and controlled by a spring.

An instrument having the same general appearance as that shown in figure 546 is illustrated in figure 547, but it is constructed and calibrated for measuring potential. A platinum-silver-alloy wire is stretched between the points A and B, and a phosphor bronze wire between points C and F. When the platinum wire expands from the heat produced as the current passes through it, the tension of the wire CF is reduced, which gives a little slack to the silk thread HE, permitting this to be pulled to the left by the spring S. The thread is turned around the shaft and causes the pointer to move correspondingly. The aluminum disc, D, is for damping of the movements. The disc moves between the ends of a permanent horseshoe magnet. A large resistance, R, is in series with the wire AB, so that the current is in proportion to the voltage and the resistance of AB.

Hot-wire instruments are independent of frequency, can be used on either direct or alternating current, giving in the latter case the true *effective* value of the alternating current in heat produced. However, they are more easily damaged or burned out than other types of measuring instruments. They are also subject to slight errors in reading due to changes in temperature.

The "hot-wire" element, if any considerable current is to be passed through the meter, is in practice either a number of wires, or a wide strip of thin metal. The material, in ordinary commercial meters, is usually an alloy of about 60 per cent copper and 40 per cent nickle, known under the trade name of Constantan, Advance, etc.

Hot-wire ammeters and hot-wire "wattmeters" are frequently used in wavemeters for indicating resonance. When so employed, they are usually inductively coupled to the wavemeter proper, so as to remove the resistance of the hot-wire element from the circuit of the latter. The hot-wire "wattmeter" is in reality a *current-square meter,* of the expansion type, giving deflections in proportion to the current consumed within the instrument itself. The readings given are proportional to the current squared.

435. The *thermo-coupled instrument* is used almost exclusively for determining the effective value of the high-frequency antenna current in radio transmitters. This is arranged with a calibrated shunt, as described in paragraph 427, and the portion of the current which is used for obtaining the measurement of the quantity in the antenna is employed in the following manner: Two wires of dissimilar materials, one of them usually being antimony, are fastened to the single wire, and the joint, J, is welded. This makes a small divided circuit from A to B through J. As the permeability of the dissimilar metals is different, heat is created at the joint J. Heat created in this manner will

cause a small voltage from Z to W, or vice versa, according to the metals used. This is a direct current and always in the same direction. A small d. c. millivoltmeter is connected in series with W and Z. While this actually registers only the potential set up by the joint J, this is an exact ratio to the square of the current in the external circuit, so that by properly calibrating it, the instrument may be used for indicating effective current in amperes. On account of the heat developed being in proportion to the square of the current, and the indications of the meter changing as the square of the current, the scale on this type of instrument is not uniform. As the pointer moves toward the right-hand side of the dial the spaces on the dial are necessarily farther apart to give an accurate reading.

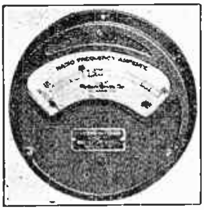


Fig. 549. Roller-Smith Thermo-Coupled Antenna Ammeter.

A new type of thermo-coupled ammeter, called a *current-transformer meter,* has recently been developed, and has met with favor among radio engineers. This has the small galvanometer and thermal junction, as shown in figure 548, but instead of the calibrated shunt in series with the line, a toroidal iron-cored coil is connected in series with the junction. This serves as the secondary of a compact transformer. The primary is a single turn of heavy wire, looped around the secondary, and in series with the circuit of which current is to be measured. The high reactance of the secondary, plus the high resistance of the thermal junction, results in a *step-down of the current,* and, with proper calibration, the instrument can be used for measuring large values of current without danger of burning out. The meter may also be of smaller size than would otherwise be possible.

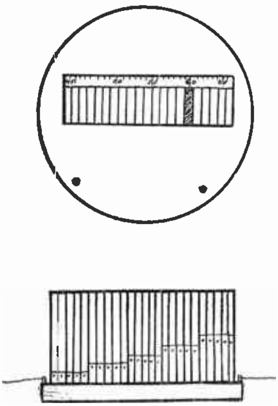


Fig. 550. Reed Frequency Meter.

436. In the more elaborate installations of radio apparatus a *frequency meter* is generally included. Sometimes a power-factor meter is provided also. The frequency meter may be designed for indicating fre-

quencies of 500 cycles or less, and may be of the vibrating reed type, or operated by electro-magnetism. The fundamental working part of the reed frequency meter is shown in figure 550. A number of steel "reeds" are mounted so that they can vibrate freely at their own natural period, on the order of tuning fork vibration. The reeds are mounted on the iron core of an electromagnet. The coil of this is connected in shunt to the output of an alternator, and is composed of fine wire, as in a voltmeter. The reeds are chosen for particular frequencies and mounted so that their vibration period will read consecutively from left to right. Then with this mounted as shown in the upper illustration in figure 550, the frequency of the current can be determined. The reed which vibrates in unison with the alternating-current frequency which is exactly in synchronism with its own natural period of vibration makes a shadowy blur which is plainly visible. The other reeds do not vibrate at the same time.

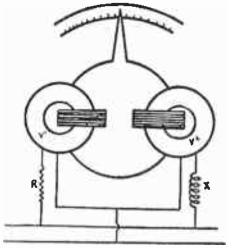


Fig. 551. Westinghouse Frequency Meter.

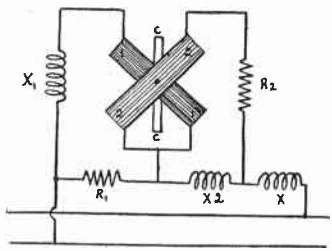


Fig. 552. Weston Frequency Meter.

Two makes of electrodynamic frequency meters are illustrated in figures 551 and 552. The Westinghouse frequency meter contains two voltmeter movements arranged so that they tend to rotate in opposite directions. The reactance of the inductance X varies with the frequency, thus varying the amount of current through it. This causes the pointer to move in proportion to the changes in frequency. The apparatus is calibrated for current of the frequency with which it is to be used.

The Weston frequency meter contains two fixed coils, 1, 1, and 2, 2, and a movable soft-iron vane. The latter takes a position according to the magnetic field produced by the two coils. Current through coil 1, 1, decreases when the frequency is increased. At the same time the current through 2, 2, is increased. The series coil X is for damping the higher harmonics.

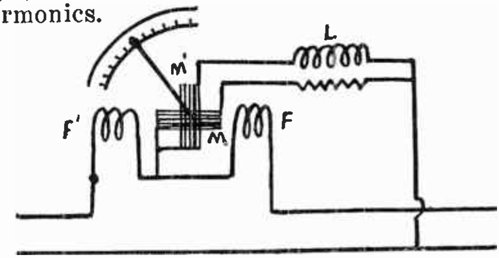


Fig. 553. Weston Power-Factor Meter, Single-Phase.

437. A *power-factor meter* is somewhat similar in design to a wattmeter, consisting of series current coil and shunted voltage coil, but there are two windings connected in the movable part of the apparatus. In figure 553, M M′ is the moving system, one coil, M, being connected in shunt to the line and in series with a resistance, while the other coil is connected in series with an inductance. It is obvious that the current in coil M′ will be about 90° out of phase with the current in coil M. When the power factor is unity, the reaction between these two coils will be minimum, and the torque produced by the effect of M′ on M, will cause the moving system to take a position with the plane of M parallel to that of F′ and F. The mark on the scale at this point will be 100. When the power factor is zero, coil M′ exerts

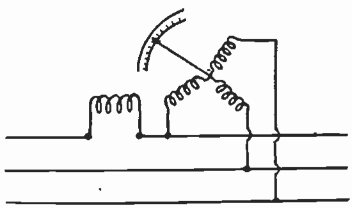


Fig. 554. Three-Phase Power-Factor Meter.

all of the torque and causes the moving system to turn so that the plane of M′ is parallel with the plane of F′ and F. Theoretically, the frequency will affect the indications, as the current in L depends upon the frequency. However, by careful design of the coil L, its reactance will neutralize moderate frequency variations.

In figure 554 is shown the circuit arrangement used in *three-phase power-factor meters.* The additional inductance is not required, as this is not affected by the frequency as is the meter shown in figure 553. The moving system consists of three coils, connected to the line in the same manner as the primary of a three-phase transformer. The principle by which it indicates the power factor is the same as in the single-phase instrument. The moving system takes positions according to the average power factor of the circuit.

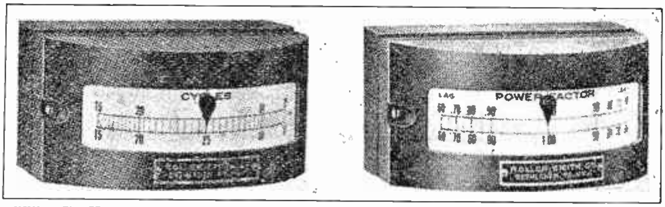


Fig. 555. Roller-Smith "Horizontal Edgewise" Frequency Meter and Power-Factor Meter.

The frequency meter and the power-factor meter may be mounted in the usual style of cases having circular faces, or they may be put up as shown in figure 555. These are neat and convenient on switchboards where space is valuable.

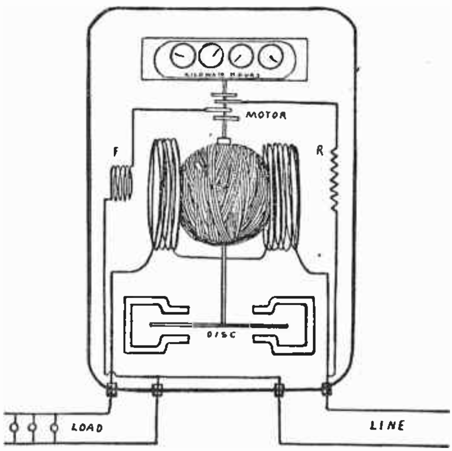


Fig. 556. Thompson Kilowatt-Hour Meter.

438. Instruments for measuring power which comes into buildings, and according to which electric power bills are paid, are *kilowatt-hour meters.* These are sometimes referred to as *energy* meters. Fig. 556 shows the working principles of a direct-current kilowatt-hour meter. This consists of a hollow spherical armature coil, having no iron about it in any way, equipped with a delicate commutator, and operated as a motor between two hollow field coils. As there is no iron about the magnetic circuit, the magnetic field produced is exactly in proportion to the current in the field coils. The current in the armature is also proportional to the voltage of the line. Hence the torque is in proportion to the power. A load is provided, which produces a drag on the motor in proportion to the speed. This is necessary in order that the speed of the motor be kept in proportion to the power passing through the meter. This load is usually obtained by attaching an aluminum disc to the end of the motor shaft and rotating it between the fields of two permanent horseshoe magnets. As the disc revolves, eddy currents are produced in it by the fields of the magnets, and a back emf. is built up, producing a counter torque, against the direction

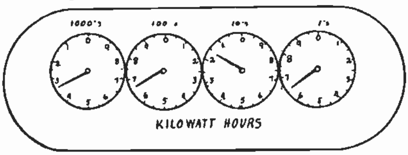


Fig. 557. Kilowatt-Hour Meter Dials.

of rotation of the motor. This is always in proportion to the speed, for as the speed increases the counter torque must increase in proportion also. The result is that the speed of the motor is fairly constant, averaging about 25 r.p.m., and varying little under changes of power. The torque exerted is registered by clockwork gears at the upper part of the instrument, and these operate the indicating pointers. The gear ratio of this register mechanism is the actual meter, and the rest of the apparatus is a motor with a magnetic brake for operating it.

The dials may be made to read as shown in figure 557, or in 10,000s, 1,000s, 100s and 10s, or otherwise in special cases. The hands of the dials follow from the number 1 around the dial. For instance, if they were in the position indicated in figure 557, and the readings were as indicated above the dials in this illustration, the power bill would be for 3,616 kilowatt hours.

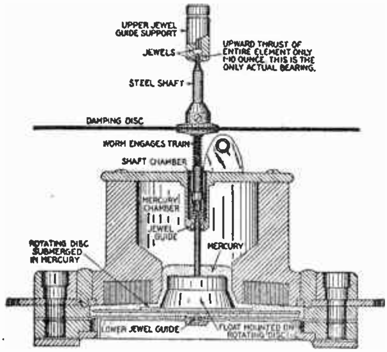


Fig. 558. Cross-Section of Sangamo Mercury Ampere-Hour Meter.

It can be seen, in figure 556, that the field windings of the motor are in series with the line, and the armature in shunt, as is the voltage coil of the indicating wattmeter. The usual protective resistance is placed in series with the armature coil. The coil F, in this diagram, is an adjustable shunt field coil. The function of this is to compensate for slight losses of power due to the friction of the rotating armature. This compensating field coil is mounted in a plane parallel to one of the main field coils, and arranged so that it can be moved back and forth to obtain just the proper relation between the two coils to maintain a balance If this is not perfect, the meter may "creep," or register power when the consumer is not using power.

Various types of kilowatt-hour meters for alternating current, single and polyphase, are based on the principles of the induction motor, and known as induction kilowatt-hour meters.

Connections to a Sangamo Ampere-hour Meter are shown in figure 480. A more detailed illustration is given in figure 558.

This meter is an adaptation of the mercury motor, invented by Faraday. A copper disc is floated in a pan of mercury, mechanically sealed, between the poles of a permanent magnet. As current is sent through the mercury and disc, the magnetic field set up is at right angles to that of the permanent magnets, and the effect is rotation. By attaching the pointer to the shaft of this motor through gears which cause it to move opposite to the direction of rotation of the disc, we have a means of measuring the current passing through the motor. The rate of current flow corresponds to the speed of the disc, and by calibrating this to read in ampere-hours, we have the ampere-hour meter.

439. The measurement of resistance is one of the most elementary of measurements, but it has a wide range of

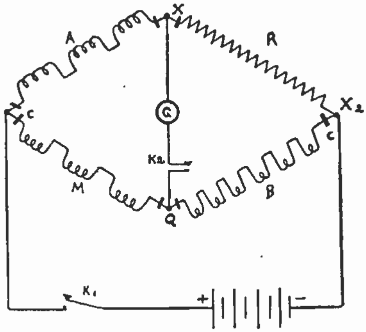


Fig. 559. Circuit of Wheatstone Bridge.

applications, in fact, enters either directly or indirectly into most of the measurements and calculations made in general or radio electrical work. The most fundamental resistance meter is the *Wheatstone bridge.* This may be made up in lozenge pattern, laid out exactly as shown in figure 559, or it may be arranged with point Q variable, and resistances M and B portions on a single "slide-wire." Referring to figure 559, if the resistance of the branch A X R is the same as that of M Q B, there will be no difference in the potential of these two branches, the same current will flow through each branch, and being no difference across the line X Q, no current will flow across this, and the galvanometer will give a reading of zero. If the resistances of A, M and B are known quantities, the calculation of the resistance of R is a simple matter. Suppose we have a number of standard resistance coils, arranged for plugging into contacts c. We use a 10-ohm resistance for A, a 10-ohm one for M, and another 10-ohm unit for B. We then attach our unknown resistance between the points X and X_2, and the galvanometer needle deflects considerably, when we press the keys K_1 and K_2 simultaneously, indicating current passing across the galvanometer bridge. We try a 25-ohm resistance in B, and the galvanometer needle deflects again, but in the opposite direction. After several experi-

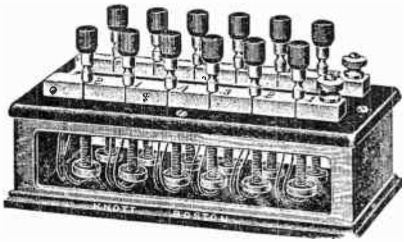


Fig. 560. Standard Resistance Box.

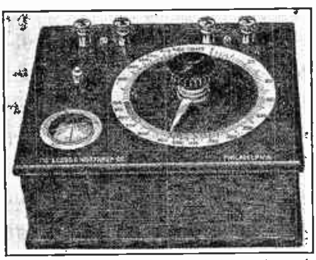


Fig. 561. Leeds and Northrup Ohmmeter.

ments with B we find that when we insert a resistance of 17.5 ohms in this place in the circuit that the gavanometer indicates no current. Hence, the resistance of the upper branch must be equal to that of the lower branch, or the resistance of the unknown quantity must be 17.5 ohms. A rheostat, having calibrated taps, for calibrated resistances is frequently employed in the location of B in the Wheatstone bridge.

An ohmmeter is shown in figure 561. The battery is connected to the two binding posts at the left, and the unknown resistance to be measured across the two at the right, marked X. A push button operates the double key, and the knob provides control of a variable resistance connected in a bridge circuit enclosed within the case. A calibrated dial gives readings directly in ohms.

440. The *slide-wire* bridge resistance meter is illustrated in figure 562. This is an arrangement frequently used by students, or on school lecture tables. A length of wire having a high resistance is stretched taut between points A and B. Directly under this wire is a double scale marked off in 1000 sections, with a zero at each end, so that readings can conveniently be taken from either end as the stylus is moved toward the left or right along the wire. This operates on the same general principle as the Wheatstone bridge, but in this device the potentials are balanced by moving the slider along the high-resistance wire, which varies the relative resistance of C and D. A standard resistance spool is connected at E, and the resistance to be measured across the binding posts at X. One terminal of the galvanometer is permanently attached to the post P, while the other one is connected to the slider contact. With the unknown resistance

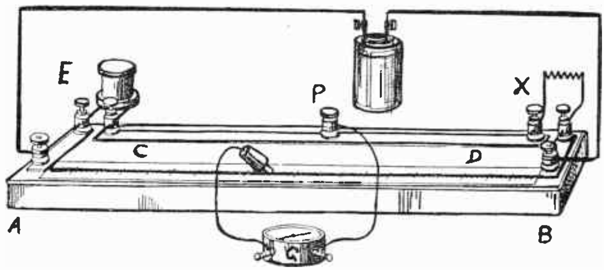


Fig. 562. Slide-Wire Resistance-Measuring Bridge.

across X, we can move the slider along the wire until the galvanometer needle is not deflected. The length from S to A is read from the scale, and also the length from S to B. Then the resistance of X may be determined by the following formula:

$$\frac{\text{Resistance E}}{\text{length A}} = \frac{\text{Resistance X}}{\text{length D}}, \text{ or, } X = \frac{E \times D}{A}$$

The lengths of the portions of the slide wire are used, as the resistance is in the same proportion.

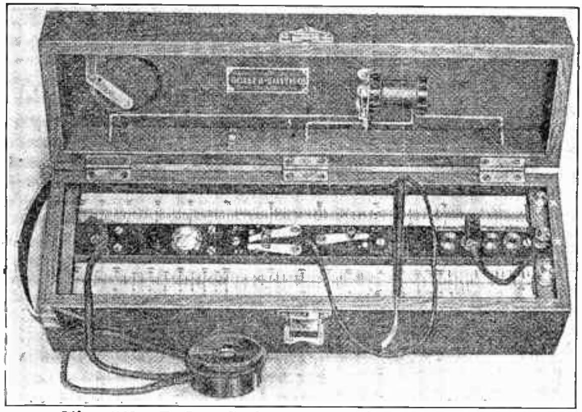


Fig. 563. Roller-Smith Type-GOM Ohmmeter.

Many makes of slide-wire ohmmeters are on the market, being usually calibrated to give readings directly in ohms. The meter shown in figure 563 is a portable commercial type of instrument. This contains a D'Arsenval galvanometer,

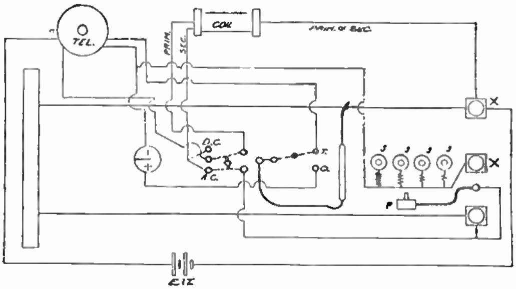


Fig. 564. Diagram of Roller-Smith GOM Ohmmeter.

self contained dry-cell battery, and an induction coil. A telephone is also included. By means of one switch either the telephone receiver or the galvanometer may be used at will for detecting a state of balance, and by means of another switch the battery current is either applied direct or used to excite the induction coil. The galvanometer enables the use of the instrument in locations where there is too much noise to permit of the employment of the telephone receiver, and is more sensitive on direct current than the latter. By obtaining alternating current from the secondary of the induction coil, the instrument is applicable for measuring the resistance of electrolytes and for the comparison of inductances and capacities. The plug, P, may be inserted into any of the jacks, shown at the center right of the diagram, thus giving a choice of four standard resistances of different value. Practical line men use meters of this type in locating faults and breaks in power lines.

441. The simple slide-wire type of *potentiometer* is useful for *comparing voltages,* and factory-made instruments built on this principle are on the market, being rated as low-potential or high-potential, according to the resistance of the slide-wire, and the approximate power on which they are to be used. The fundamental principle is indicated in figure 565. Standard cells of known potential, in series with a standard tapped rheostat, R, are connected across a slide-wire calibrated resistance, W, under which is the usual scale, which may be calibrated to read in proportions of the total resistance of the wire, or directly in volts. The standard voltage is represented as E, and the unknown as X. By throwing the switch so that E is in shunt to the resistance

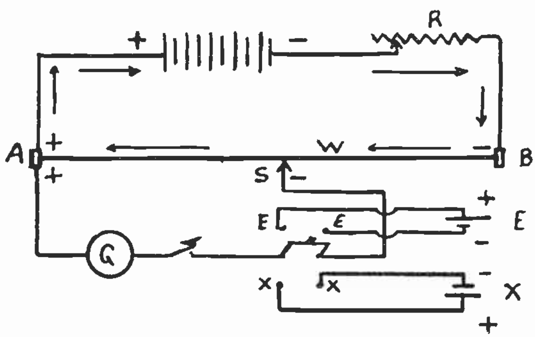


Fig. 565. Slide-Wire Potentiometer.

W, its voltage can be determined by moving S over the latter until the galvanometer indicates zero deflection. At this adjustment the volt drop between S and A is equal to the voltage of E, and no current can flow in either direction through the galvanometer. If the volt drop between A and S, along W, is greater than the voltage of the cell, a current will be forced through the cell E in a direction opposite to its polarity, or if this volt drop is less than the voltage of the cell, current will flow around the circuit consisting of the cell E and the section of the slide-wire in series with it. After the balance has been obtained from the standard, the voltage of X is determined by comparison.

442. Ohmmeters are also manufactured operating on the electromagnetic principle. These instruments have the same general external appearance as magnetic types of ammeters and voltmeters. They contain a permanent horseshoe magnet, between the poles of which a rotating coil is mounted, with a pointer attached. The coil is divided into two equal

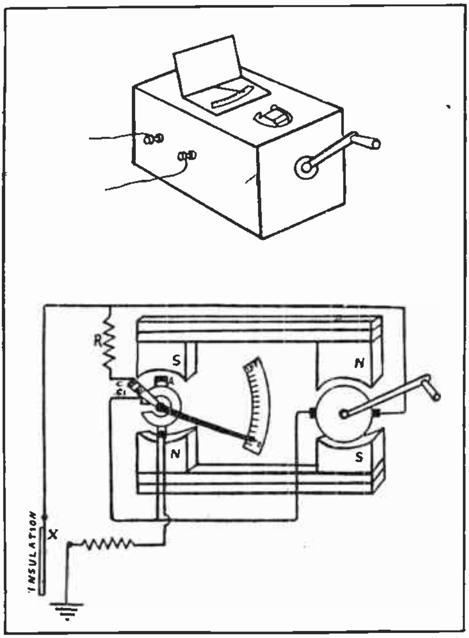


Fig. 566. Megger.

parts, connected respectively in two branch circuits in each of which is a known resistance unit. The deflection of the needle then is dependent upon the value of the unknown resistance connected to the meter. A combination of this type of ohmmeter and a hand-operated magneto, used for measuring high resistances, such as that of the insulation of buried lines, etc., is sold under the name of a *"megger,"* by James G. Biddle, Philadelphia. If nothing is connected across the terminals at X, and the generator turned by hand, current will flow through the coils C and C1, connected in series. This sets up a magnetic field which drives these coils to the position directly over the open plate in the C-shaped piece of iron around which they move. This brings the pointer to the point on the scale marked inf, or "infinity." If a high resistance is then connected across X, a divided path is provided for the current from the generator, part of it passing through the coils C and C1, and a portion of it going through the unknown resistance, and the coil A in series with it. The current in coil A sets up a magnetic field in opposition to that in C C1, and the torque thus produced drives the pointer in the opposite direction on the scale. The scale is calibrated to indicate the value of the external resistance across X, which must cause the needle to stop at any particular position. These instruments may be used for testing the insulation of motors, house wiring,

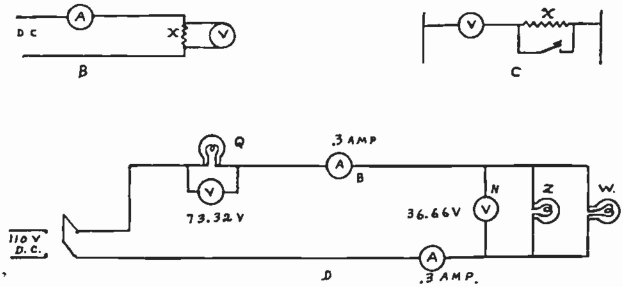


Fig. 567. Voltmeter and Ammeter Measurements of Resistance.

power or telephone lines, etc. For testing the insulation of a buried line, one terminal of X may be grounded. If the reading indicates that the resistance is low, compared with what it should be under such conditions with wire having good insulation, this shows that current is escaping through the insulation and returning by way of the ground.

443. Measurements of resistance are possible with ammeters and voltmeters, and are sometimes most conveniently made in this manner. In figure 567, B shows how the volt drop across an unknown unit can be used for learning the resistance of this unit. A simple application of Ohm's law gives the result. Referring to the rule for line drop, as in paragraph 70, we find that the resistance in a portion of a circuit in which there is a certain voltage drop is equal to the voltage across the section of line divided by the current passing through this section,

$$\text{or } R = \frac{E}{I}$$

If the ammeter, in B, figure 567, shows 2 amperes flowing through the circuit, and the voltmeter, when shunted across the unknown resistance, gives a reading of a potential difference of 36 volts, the resistance X is 18 ohms. This method of measuring resistances is common in shops. If the resistance is low, as for instance in a dynamo winding, a millivoltmeter will be required to obtain an accurate reading, or if a high resistance is to be measured, where a small quantity of current is passing, a milliammeter will prove most satisfactory.

C shows a method often used in practical work, especially for the measurement of high resistances. A voltmeter only is used, no ammeter being necessary. The voltmeter and unknown resistance are connected in series, the latter being shorted by a switch or key. The voltmeter may be across a line, or from brush to brush of a d. c. generator. With the key closed, the voltage reading depends solely upon the internal resistance of the voltmeter itself, but when the key is opened, the difference in the voltmeter reading is in proportion to the value of the added resistance. Then the value of this unknown quantity is equal to the internal resistance of the voltmeter multiplied by the voltage without X divided by the voltage with X less one, or

$$X = r \left(\frac{V^1}{V^2} - 1 \right)$$

At D, in figure 567, is a practical application of the law of line drop to different parts of a circuit. Three lamps, Q, Z and W, are placed as shown in a 110-volt d. c. circuit. A voltmeter is shunted around lamp Q, and gives a reading of 73.32 volts. At the same time the ammeter shows .3 ampere flowing through the lamp. Hence, according to Ohm's law, the resistance of this lamp is 244.4 ohms. The lamp in series causes a line drop of 73.32 volts, and the voltmeter, when placed across the line as at N, gives a reading of only 36.66 volts available for the two lamps, Z and W, in parallel. The ammeter when placed on the other side of the circuit, as at the lower part of this diagram, still draws .3 of an ampere. The total resistance of the two parallel lamps must be equal to 36.66 divided by .3 or 122.2 ohms. Hence the resistance of each lamp singly is 244.4 ohms. A lamp with a resistance of 244.4 ohms to be used on a 110-volt circuit should draw .45 ampere to operate on full power, hence the three lamps burn only dimly on account of the voltage drop caused by placing lamp Q in series with the parallel group Z and W.

444. *Measurements involving radio frequencies* are more complicated than those used for direct current or low-frequency alternating current, and frequently less definite. The apparent, or effective, resistance of a wire increases with the frequency, due to the "skin effect," as explained in paragraph 333. Dr. J. A. Fleming says, in his *Principles of Electric Wave Telegraphy:* "The measurement of high-frequency currents and potentials and other specific qualities of electric conductors and insulators, when subjected to the action of electric oscillations, to a considerable extent calls for the employment of special instruments and methods. Processes used for low frequency are not always applicable to high-frequency measurements."

In radio-frequency circuits the current is usually measured with hot-wire instruments such as illustrated in figures 545, 546 and 548. These indicate the mean value of the current amplitudes as indicated by the heat produced. Voltmeters are less reliable in radio-frequency circuits on account of the effects of inductance and capacity. The measurement of the frequency itself is accomplished by an application of the principle of resonance, and in the apparatus based on this we have the *wavemeter,* which may be calibrated to give readings in frequencies or directly in wave lengths in meters.

445. The *wavemeter* is one of the most important instru-

ments used in radio work. In general its various uses may be summed up as follows:

(1) To determine the fundamental wave length of an antenna.

(2) To calibrate the antenna circuit or primary circuit of a transmitter to a given wave length.

(3) To determine the coupling between the radio-frequency circuits of a transmitter, and the degree of purity of the emitted wave.

(4) To measure the logarithmic decrement of a spark transmitter.

(5) To determine the wave length of a distant transmitter.

(6) To calibrate a receiving set to a desired wave length.

(7) To place any two circuits having inductance and capacity in resonance with each other.

(8) To measure the capacity of another condenser, or the inductance of a coil.

(9) To calibrate another wavemeter.

446. Measurements of wave lengths radiated from antennæ or other oscillating circuits was treated in an elementary way in paragraphs 205 and 206, and a few fundamental wavemeter circuits are shown in figure 137. The wavemeter consists essentially of a variable calibrated condenser and variable calibrated inductance. The latter usually consists of a number of separate coils of fixed inductance which can be inserted into a jack, the wave length

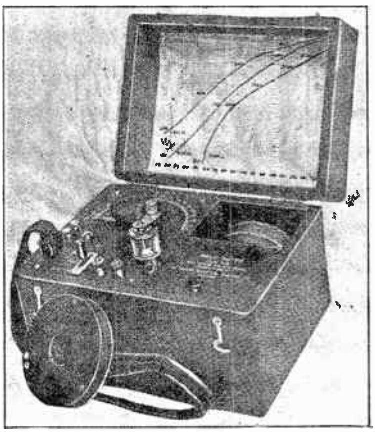


Fig. 568a. De Forest Wavemeter.

readings of the condenser having been calibrated separately for each one of these plugged-in inductances, and indicated as such on the dial, or shown on a calibration curve. A simple type of wavemeter is shown in figure 568a. The calibration curve pasted inside of the cover shows the wave lengths indicated by the meter for coils 1, 2 or 3, with settings of the condenser as indicated across the bottom of the chart. Either a crystal detector and telephone or glow-lamp may be used for indicating resonance. The switch at the lower left is used for throwing the connections to one or the other.

The indicating device used with a wavemeter may be a lamp, crystal or vacuum-tube detector with telephone, or a milliammeter or hot-wire milliwattmeter. The latter devices are somewhat more accurate. The meters are often magnetically coupled to the circuit containing the wavemeter inductance and capacity so as to remove their resistance from the latter circuit, and when used with a step-down transformer, as is frequently done, a greater amount of current is obtained for their operation.

As the capacity and inductance of the wavemeter are calibrated, any adjustment of this will give an indication of the wave length, or frequency, at that particular setting, of oscillations inductively picked up by the wavemeter coil. When a transmitter of which the wave length is to be measured, is adjusted to give the greatest indication of energy induced into the wavemeter, when the latter is placed a few feet from the radiating circuit, this wave length can be determined from the wavemeter setting, because at this particular setting the two circuits are in resonance, or vibrating at the same frequency. With a known inductance and a capacity setting at resonance, this frequency is

$$F = \frac{1}{2\pi\sqrt{LC}}$$

and as shown in paragraph 210, the wave length is the quotient of velocity divided by frequency. In modern wavemeters the actual wave length is usually engraved on the dial of the condenser, making calculations unnecessary, unless it is desired to reduce this reading to kilocycles.

447. *To tune a transmitter to a given wave length,* all that is necessary is to make a curve of the various wave lengths obtained at resonance with the wavemeter,

for various adjustments of the inductance of the transmitter, and to mark this so that by referring to the curve thus made, it will be possible to adjust the transmitter to these wave lengths afterwards. If the apparatus is inductively coupled, this type of a curve is made of the circuit containing the oscillation transformer primary, and then the antenna wave length may be taken separately, and a third curve made after the two circuits are coupled together. But in practice the antenna circuit is generally tuned to resonance with the first circuit by use of the antenna ammeter. This indicates the adjustment at which the greatest transfer of energy takes place and at which the antenna circuit must be in resonance with the primary circuit.

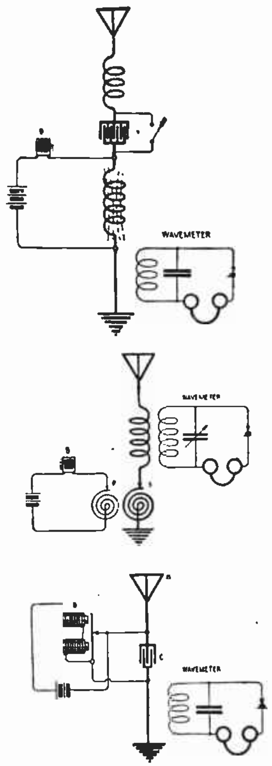


Fig. 568b. Methods of Employing a Buzzer for Exciting an Antenna into Oscillation.
(Elmer E. Bucher.)

To take a separate wave length measurement of the antenna circuit it is necessary to excite it into oscillation independently of the primary circuit. This may be accomplished by means of a buzzer coupled inductively to the antenna, or shunted around a condenser placed in series in the antenna system. Or a vacuum-tube oscillator may be used. A spark gap across the secondary of an induction coil has been used for this purpose, but on account of this causing an interfering wave to be radiated while the measnrements are being made, it is now taboo. With the antenna set into oscillation, the fundamental wave length can be determined, and then a curve made as inductance is added, or the effects of a short-wave condenser studied. After the antenna system is tuned to the desired wave length, and coupled to the primary circuit, it is necessary to take another wavemeter reading to learn the exact result of coupling the two circuits together. This will show the extent of a second wave, if this exists, and indicates the degree of purity and sharpness of the radiated waves. In this measurement a curve is made showing the energy induced into the wavemeter at different wave length settings. If two waves are being emitted, the wavemeter can be tuned to resonance with the transmitter at a given setting of the latter, on two different settings. By use of the curve showing the energy induced into the wavemeter at each one of these, the relative amplitude of the second wave can be determined, and after several tests of this kind, in conjunction with efforts to correct the cause of the second wave, this may be used as a guide in reducing the energy of the latter. A graph of an impure wave is shown in figure 134, a sharp wave in figure 135, and a resonance curve showing wave lengths obtained on different settings of inductance in figure 138.

For vacuum-tube transmitters a wavemeter consisting of merely a calibrated inductance and capacity without detector is convenient. Resonance is determined by a drop in the antenna ammeter reading, due to the absorption of the wavemeter.

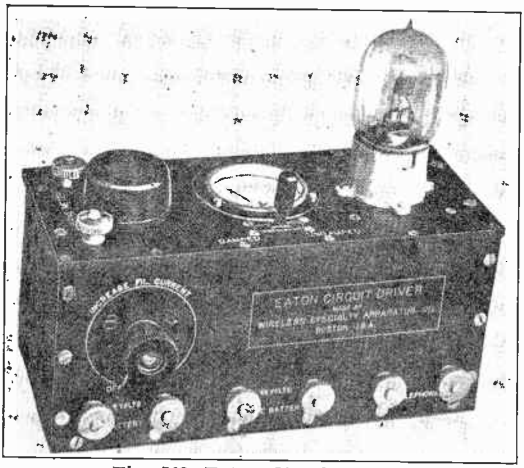


Fig. 569. Eaton Circuit-Driver.

448. In cases where it is desired to tune a circuit, which of itself does not produce oscillations, to a wavemeter setting, it is desirable to excite the wavemeter into oscillations of the calibrated frequency. This may be done with a buzzer or vacuum-tube oscillator. Such circuits are usually called circuit-drivers. Figure 569 is an illustration of

a circuit-driver and wavemeter which is used in the U. S. Navy.

When used for *calibrating a receiving set,* so that its settings may be marked for various wave lengths, the circuit-driver acts as a miniature transmitter, and is placed a few feet away from the receiver and the receiver tuned until the oscillations of the wavemeter are received at the greatest resonance, at which the receiver is oscillating at the period of the meter. Piezoelectric crystals have been found useful for producing oscillations of standard frequencies for measurements and calibrations.

449. Several makes of wavemeters have been manufactured which have additional equipment for determining the *decrement* of radiated damped waves. The decremeter is probably the last word in measuring instruments, as it is a long way from the original galvanometer for simply indicating a weak electric current, to the direct reading decremeter, which gives in direct figures on dials the calculation of the ratio of the damping of successive waves in a radiated wave train. The Kolster decremeter shown in figure 570 was perfected by Dr. Frederick Kolster, for several years at the head of the radio laboratory of the Bureau of Standards. In the *Bureau of Standards Circular No. 74,* we find, "A decremeter is a wavemeter conveniently arranged for measurements of

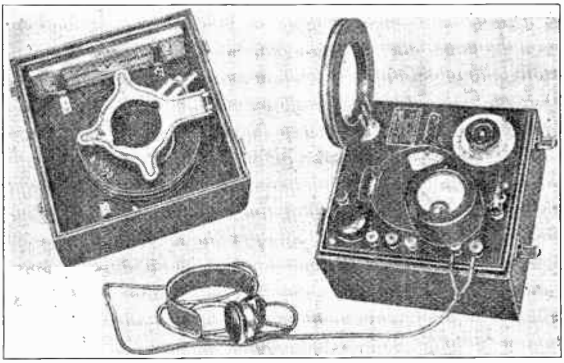


Fig 570. Kolster Decremeter.

resistance or decrement. The forms usually employed make use of the reactance-variation method. While, of course, resistance can be calculated from a measured value of decrement, the principal application of the decremeter is in the measurement of the decrement of a wave. Another important use is in the measurement of phase difference of a condenser. Since the decrement due to a condenser is π times its phase difference; if desired, the scale may be calibrated in terms of phase difference instead of decrement.

In the usual use of the reactance-variation method of determining decrement, the current Ir is observed when the condenser is adjusted to the value Cr to produce resonance, and the condenser is then changed to another value C and the current I_1 read. When the second condenser setting is such that the I_1^2 is equal to ½ Ir^2, the decrement is calculated by

$$d' + d = \pi \frac{\pm (Cr - C)}{C}$$

A certain value of decrement therefore corresponds to that displacement of the condenser's moving plates which varies the capacity by the amount (Cr — C). The displacement for a given decrement will in general be different for different values of C, the total capacity in the circuit. At each point of the condenser scale, therefore, any displacement of the

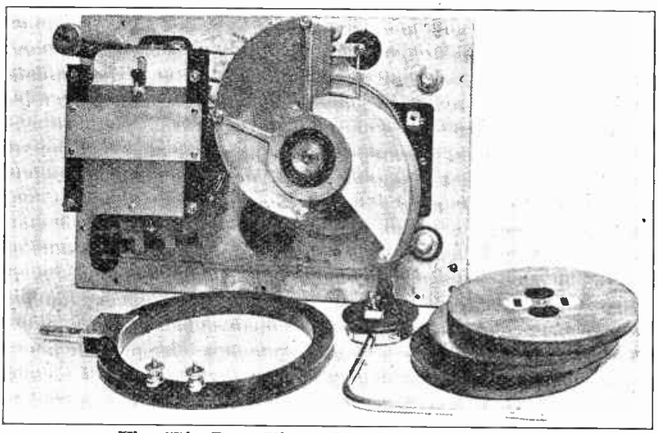


Fig. 571. Rear View of Kolster Decremeter.

moving plates which changes the square of current from Ir^2 to ½ Ir^2 means a certain value of (d′ + d). A special scale may therefore be attached to any condenser with graduations upon it and so marked that the difference between the two settings is equal to the decrement. The spacing of the graduations at different parts of the scale depends upon the relation between capacity and displacement of the moving plates. When this relation is known, the decrement scale can be predetermined. A scale may therefore be fitted to any condenser, from which decrement may be read directly, provided the capacity of the circuit is known for all settings of the condenser. The decrement scale may be attached either to the moving-plate system or to the fixed condenser top. It is usually convenient to attach it to the unused half of the dial opposite the capacity scale. The value of the decrement determined by this method is $(d' + d)$, where d is the decrement of the instrument itself. This must be known from the calibration of the instrument, the value of d', the decrement of the wave under measurement being then obtained by subtraction. It is easy to make a decremeter out of a circuit having a condenser with semicircular plates. Such condensers follow closely the linear law,

$$C = a\theta - C_0,$$

where θ is the angle of rotation of the moving plates and a and C_0 are constants. It can be shown that the decrement

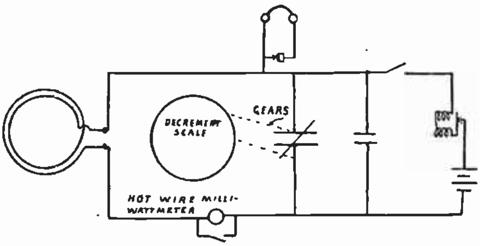


Fig. 572. Diagram of Kolster Decremeter.

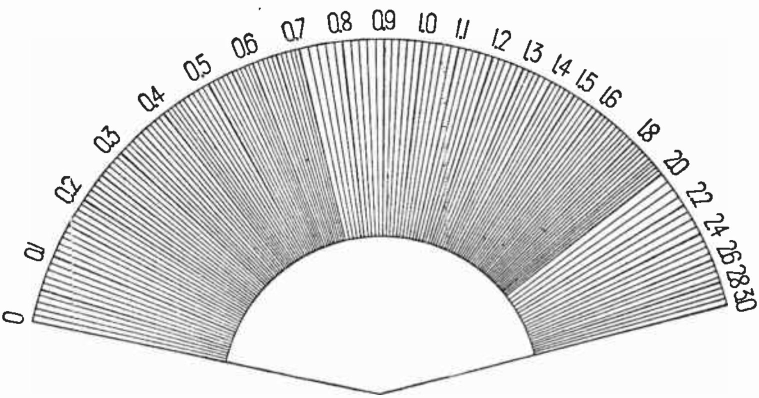


Fig. 573. Direct-Reading Decrement Scale. (Bureau of Standards.)

scale applicable to such a condenser is one in which the graduations vary as the logarithm of the angle of rotation. This scale has been calculated and is shown in the accompanying figure. It has been calculated to fit the equation

$$d' + d = \pi \frac{C_2 - C_1}{C_2 + C_1}$$

This scale may be cut out and trimmed to fit the dial and then affixed to the condenser with its 0 point in coincidence with the graduation which corresponds to maximum capacity."

A condenser shaped like the one shown in figure 571 has a variation of capacity exactly in proportion with the square of the angular displacement of the plates. These are known as "straight-line" condensers, because when a graph is made of the capacity, or of wave lengths in meters in a circuit in which they are used, the "curve" will be a straight line. The unilateral connection of the crystal detector and telephones to the wavemeter, as shown in figure 572, removes the resistance of the crystal and telephone windings from the resonant circuit, and hence eliminates any effect that these might have on the wave length of the latter. The detector circuit is *capacitively coupled* to the oscillating circuit.

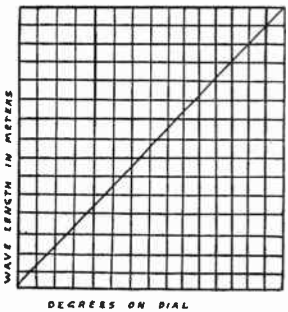


Fig. 574. Graph of a Logarithmically Designed Condenser.

450. In *measuring the decrement of a radiating circuit,* with the Kolster decremeter, the adjustment of greatest resonance is first obtained, as shown by the hot-wire current-squared meter, often referred to as a wattmeter. The condenser plates are rotated until the deflection of the wattmeter is reduced to one-half its original value. This may be caused by either a decrease or increase of capacity. The decrement scale is then set at zero. It can be rotated separately if desired. At the zero setting it is locked so that it can not rotate independently, but will move around with the condenser shaft when the condenser plates are turned. With the hot-wire wattmeter indicating one-half its orig-

inal reading at resonance, the condenser dial is now turned back to maximum resonance and past this point in the opposite direction until half this reading is again obtained by detuning the wavemeter. The reading on the scale, opposite the index mark 0, is now equal to $d_1 + d_2$. The known decrement of the wavemeter itself is indicated by d_1, and this calibration is always included with the wave meter for the guidance of operators. The actual decrement of the waves under measurement is then the difference between the total reading and d_1 or d_2. The decrease in current for a change in the capacity of the condenser is in proportion to the decrement of the waves. Several calibrations of the transmitter are usually made, at various wave lengths, with the decremeter in each case set for resonance and off resonance in each direction, until a nearly zero deflection of the wattmeter is obtained.

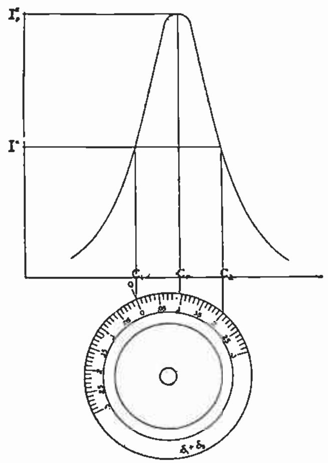


Fig. 575. Relation Between Decrement Scale and Condenser Settings.
(Robison's Manual of Radiotelegraphy and Telephony.)

The decrement of the decremeter is generally determined by "trying to measure the decrement of continuous waves." That is, the same resonance and off resonance methods are employed for measuring waves in which there exists no decrement. This quickly shows the amount of decrement caused by the meter circuits. Another method is to insert a calibrated resistance in the wavemeter circuit, after tuning it carefully to resonance with a source of damped wave oscillations. Quoting from Bucher's *Practical Wireless Telegraphy*: "After the value of $d_1 + d_2$ is obtained, the coupling between the wavemeter coil and the antenna system must not be altered. A piece of resistance wire is stretched tightly between two binding posts and connected in series in the wavemeter. The amount of wire is gauged by the sliding contact. With the pointer of the condenser set at C_r, or resonance, the spark gap is energized and resistance added until the reading of the wattmeter falls to exactly that obtained by the original resonance adjustment. The condenser of the wavemeter is then shifted to either side of resonance to such a value of capacity that will give one-half the wattmeter reading obtained at C_r. Let the capacity of the wavemeter condenser below resonance be represented by C_3 and the capacity above resonance by C_4, then

$$d_1 + d_2 + d_3 = \frac{C_4 - C_3}{C_r} \times 1.57$$

It is evident that if the value of $d_1 + d_2$ be subtracted from $d_1 + d_2 + d_3$ the value of d_3 is at once obtained." The decrement of the decremeter is then, according to Fleming and others, as follows:

Wavemeter decrement $= \frac{V' \times d_3}{2V - V'}$, where V represents the value $d_1 + d_2 = \frac{C_2 - C_1}{C_r} \frac{\pi}{2}$, and V' = the value obtained by the formula just above. So, the decrement of the antenna circuit being measured is found to be the difference between d_2 and the sum $d_1 + d_2$.

Substituting certain settings for $\frac{C_2 - C_1}{C_r}$, such as 55°, 45° and 50°, we find that $\frac{55 - 45}{50} = .2$. According to the formula this must be multiplied by $\frac{\pi}{2}$, or 1.57, which gives us .314. If we assume the decrement of the measuring instrument to be .114, and subtract this from .314, we find that the decrement of the radiated wave is .2.

451. *Measurements of the inductance and capacity of an antenna* system may be accomplished, in various ways, by the use of a wavemeter in combination with various tables and formulæ. The frequency is

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

in which L and C stand for henries and farads.

Then $$\lambda = 2\pi V \sqrt{LC}$$

with V representing velocity.

With L in microhenries and C in centimeters,

$$\lambda = 59.6 \sqrt{LC}$$

The wave length is also equal to

$$1884 \sqrt{L \text{ microhenry } C \text{ microfarad}},$$

hence the product of the inductance and capacity producing any wave length will be found to correspond as follows, with L in microhenries and C in microfarads:

$$LC = \left(\frac{\lambda}{1884}\right)^2$$

Then if either C or L can be determined independently the other value can be found by dividing the product of LC by the known value.

To determine the fundamental inductance and capacity of an antenna, it is first necessary to find the fundamental wave length. With the fundamental wave length represented as λf, and a coil of known inductance added to the antenna represented as L1, and a second wave length reading taken with this coil in series in the circuit,

$$Lf = \left(\frac{\lambda^2}{\lambda 1^2 - \lambda f^2}\right) L1 \text{ cms.}$$

$$\text{and } Cf = \left(\frac{\lambda f}{59.6}\right)^2 \frac{1}{Lf} \text{ mfds.}$$

When either the inductance or the capacity are known, the other may be easily determined by referring to the accompanying LC table.

It is necessary to increase the product LC four times in order to double the wave length of a circuit. For instance, a wave length of 1,000 meters is found to have an LC of approximately .282, and a wave length of 2,000 meters has an LC of about 1.126, which is four times the LC of 1,000 meters.

The capacity of the average ship's antenna is about .001 mfd.

See page 830 for table showing wave lengths from 1 to 100 meters.

TABLE SHOWING RELATION OF NATURAL WAVE LENGTH, FREQUENCY, AND INDUCTANCE CAPACITY PRODUCT.

(Prepared by Greenleaf W. Pickard)

Courtesy of Wireless Specialty Company

(n = frequency)

"This table gives the relation between free wavelength in meters, frequency in cycles per second and capacity-inductance product in microfarads and microhenries, for circuits between 100 and 39,000 meters. The relation between wavelength and capacity-inductance product may be relied upon throughout the table to within one part in two hundred. Three examples are given below, to illustrate important uses of the table.

Example 1. What is the natural wavelength of a circuit containing a capacity of 0.001 microfarad, and an inductance of 454 microhenries? The product of inductance and capacity is $454 \times 0.001 = 0.454$. Find 0.454 under L×C; opposite under 'meters' is 1270 meters, the natural wavelength of the circuit.

Example 2. What capacity must be associated with an inductance of 880 microhenries, in order to tune the circuit to 3500 meters? Find opposite 3500 meters the L×C value 3.45; divide this by 880, and the quotient, 0.00397, is the desired capacity in microfarads.

Example 3. A condenser has a capacity of 0.004 microfarad. What inductance must be placed in series with this condenser in order that the circuit shall have a wavelength of 600 meters? From the table, the L×C value corresponding to 600 meters is 0.1013. Dividing this by 0.004, the capacity of the condenser, gives the desired inductance, 25.3 microhenries"

Meters	n	L×C	Meters	n	L×C	Meters	n	L×C	Meters	n	L×C	Meters	n	L×C
100	3,000,000	0.00282	200	1,500,000	0.01126	300	1,000,000	0.0253	400	750,000	0.0450	500	600,000	0.0704
110	2,727,000	0.00341	210	1,429,000	0.01241	310	968,000	0.0270	410	732,000	0.0473	505	594,000	0.0718
120	2,500,000	0.00405	220	1,364,000	0.01362	320	938,000	0.0288	420	715,000	0.0496	510	588,000	0.0732
130	2,308,000	0.00476	230	1,304,000	0.01489	330	909,000	0.0306	430	698,000	0.0520	515	583,000	0.0747
140	2,143,000	0.00552	240	1,250,000	0.01621	340	883,000	0.0325	440	682,000	0.0545	520	577,000	0.0761
150	2,000,000	0.00633	250	1,200,000	0.01759	350	857,000	0.0345	450	667,000	0.0570	525	572,000	0.0776
160	1,875,000	0.00721	260	1,154,000	0.01903	360	834,000	0.0365	460	652,000	0.0596	530	566,000	0.0791
170	1,764,000	0.00813	270	1,111,000	0.0205	370	811,000	0.0385	470	639,000	0.0622	535	561,000	0.0806
180	1,667,000	0.00912	280	1,071,000	0.0221	380	790,000	0.0406	480	625,000	0.0649	540	556,000	0.0821
190	1,579,000	0.01015	290	1,034,000	0.0237	390	769,000	0.0428	490	612,000	0.0676	545	551,000	0.0836

Table Showing Relation of Natural Wave Length, Frequency, and Inductance Capacity Product—*Continued.*

Meters	n	L×C	Meters	n	L×C	Meters	n	L×C	Meters	n	L×C	Meters	n	L×C
550	546,000	0.0852	700	429,000	0.1379	850	353,000	0.203	1000	300,000	0.282	1300	230,800	0.476
555	541,000	0.0867	705	426,000	0.1399	855	351,000	0.206	1010	297,100	0.287	1310	229,000	0.483
560	536,000	0.0883	710	423,000	0.1419	860	349,000	0.208	1020	294,200	0.293	1320	227,300	0.4 0
565	531,000	0.0899	715	420,000	0.1439	865	347,000	0.211	1030	291,300	0.299	1330	225,600	0.498
570	527,000	0.0915	720	417,000	0.1459	870	345,000	0.213	1040	288,500	0.304	1340	223,900	0.505
575	522,000	0.0931	725	414,000	0.1479	875	343,000	0.216	1050	285,700	0.310	1350	222,200	0.513
580	517,000	0.0947	730	411,000	0.1500	880	341,000	0.218	1060	283,000	0.316	1360	220,600	0.521
585	513,000	0.0963	735	408,000	0.1521	885	339,000	0.220	1070	280,400	0.322	1370	219,000	0.528
590	509,000	0.0980	740	405,000	0.1541	890	337,000	0.223	1080	277,800	0.328	1380	217,400	0.536
595	504,000	0.0996	745	403,000	0.1562	895	335,000	0.225	1090	275,200	0.334	1390	215,800	0.544
600	500,000	0.1013	750	400,000	0.1583	900	333,000	0.228	1100	272,700	0.341	1400	214,300	0.552
605	496,000	0.1030	755	397,000	0.1604	905	331,000	0.231	1110	270,300	0.347	1410	212,800	0.560
610	492,000	0.1047	760	395,000	0.1626	910	330,000	0.233	1120	267,900	0.353	1420	211,300	0.568
615	488,000	0.1065	765	392,000	0.1647	915	328,000	0.236	1130	265,500	0.359	1430	209,800	0.576
620	484,000	0.1082	770	390,000	0.1669	920	326,000	0.238	1140	263,200	0.366	1440	208,300	0.584
625	480,000	0.1100	775	387,000	0.1690	925	324,000	0.241	1150	260,900	0.372	1450	206,900	0.592
630	476,000	0.1117	780	385,000	0.1712	930	323,000	0.243	1160	258,600	0.379	1460	205,500	0.600
635	472,000	0.1135	785	382,000	0.1734	935	321,000	0.246	1170	256,400	0.385	1470	204,100	0.608
640	469,000	0.1153	790	380,000	0.1756	940	319,000	0.249	1180	254,200	0.392	1480	202,700	0.616
645	465,000	0.1171	795	377,000	0.1779	945	317,000	0.251	1190	252,100	0.399	1490	201,300	0.625
650	462,000	0.1189	800	375,000	0.1801	950	316,000	0.254	1200	250,000	0.405	1500	200,000	0.633
655	458,000	0.1208	805	373,000	0.1824	955	314,000	0.257	1210	247,900	0.412	1510	198,700	0.642
660	455,000	0.1226	810	370,000	0.1847	960	313,000	0.259	1220	245,900	0.419	1520	197,400	0.650
665	451,000	0.1245	815	368,000	0.1870	965	311,000	0.262	1230	243,900	0.426	1530	196,100	0.659
670	448,000	0.1264	820	366,000	0.1893	970	309,000	0.265	1240	241,900	0.433	1540	194,800	0.667
675	444,000	0.1283	825	364,000	0.1916	975	308,000	0.268	1250	240,000	0.440	1550	193,500	0.676
680	441,000	0.1302	830	361,000	0.1939	980	306,000	0.270	1260	238,100	0.447	1560	192,300	0.685
685	438,000	0.1321	835	359,000	0.1962	985	305,000	0.273	1270	236,200	0.454	1570	191,100	0.694
690	435,000	0.1340	840	357,000	0.1986	990	303,000	0.276	1280	234,400	0.461	1580	189,900	0.703
695	432,000	0.1360	845	355,000	0.201	995	302,000	0.279	1290	232,600	0.468	1590	188,700	0.712

Table Showing Relation of Natural Wave Length, Frequency, and Inductance Capacity Product—*Continued.*

Meters	n	L×C	Meters	n	L×C	Meters	n	L×C	Meters	n	L×C	Meters	n	L×C
1600	187,500	0.721	1900	157,900	1.015	2400	125,000	1.621	3000	100,000	2.53	3600	83,400	3.65
1610	186,300	0.730	1910	157,100	1.026	2420	124,000	1.548	3020	99,400	2.57	3620	82,900	3.69
1620	185,100	0.739	1920	156,300	1.037	2440	122,900	1.676	3040	98,700	2.60	3640	82,400	3.73
1630	184,000	0.748	1930	155,400	1.048	2460	121,900	1.703	3060	98,100	2.64	3660	82,000	3.77
1640	182,900	0.757	1940	154,600	1.059	2480	121,000	1.731	3080	97,400	2.67	3680	81,500	3.81
1650	181,800	0.766	1950	153,800	1.070	2500	120,000	1.759	3100	96,800	2.70	3700	81,100	3.85
1660	180,700	0.776	1960	153,100	1.081	2520	119,000	1.787	3120	96,200	2.74	3720	80,700	3.90
1670	179,600	0.785	1970	152,300	1.092	2540	118,100	1.816	3140	95,600	2.78	3740	80,200	3.94
1680	178,500	0.794	1980	151,500	1.103	2560	117,200	1.845	3160	95,000	2.81	3760	79,800	3.98
1690	177,400	0.804	1990	150,800	1.114	2580	116,300	1.874	3180	94,400	2.85	3780	79,400	4.02
1700	176,400	0.813	2000	150,000	1.126	2600	115,400	1.903	3200	93,800	2.88	3800	79,000	4.06
1710	175,400	0.823	2020	148,500	1.148	2620	114,500	1.932	3220	93,200	2.92	3820	78,600	4.11
1720	174,400	0.833	2040	147,100	1.171	2640	113,600	1.962	3240	92,600	2.96	3840	78,200	4.15
1730	173,400	0.842	2060	145,600	1.194	2660	112,800	1.991	3260	92,000	2.99	3860	77,700	4.19
1740	172,400	0.852	2080	144,200	1.218	2680	111,900	2.02	3280	91,500	3.03	3880	77,300	4.24
1750	171,400	0.862	2100	142,900	1.241	2700	111,100	2.05	3300	90,900	3.06	3900	76,900	4.28
1760	170,500	0.872	2120	141,500	1.265	2720	110,300	2.08	3320	90,400	3.10	3920	76,500	4.32
1770	169,500	0.882	2140	140,200	1.289	2740	109,500	2.11	3340	89,800	3.14	3940	76,200	4.37
1780	168,500	0.892	2160	138,900	1.313	2760	108,700	2.14	3360	89,300	3.18	3960	75,800	4.41
1790	167,600	0.902	2180	137,600	1.338	2780	107,900	2.18	3380	88,800	3.22	3980	75,400	4.46
1800	166,700	0.912	2200	136,400	1.362	2800	107,100	2.21	3400	88,300	3.25	4000	75,000	4.50
1810	165,700	0.922	2220	135,100	1.387	2820	106,400	2.24	3420	87,700	3.29	4020	74,700	4.55
1820	164,800	0.932	2240	133,900	1.412	2840	105,600	2.27	3440	87,200	3.33	4040	74,300	4.59
1830	163,900	0.943	2260	132,700	1.438	2860	104,900	2.30	3460	86,700	3.37	4060	73,900	4.64
1840	163,000	0.953	2280	131,600	1.463	2880	104,200	2.33	3480	86,200	3.41	4080	73,600	4.69
1850	162,200	0.963	2300	130,400	1.489	2900	103,400	2.37	3500	85,700	3.45	4100	73,200	4.73
1860	161,300	0.974	2320	129,300	1.515	2920	102,700	2.40	3520	85,300	3.49	4120	72,800	4.78
1870	160,400	0.984	2340	128,200	1.541	2940	102,000	2.43	3540	84,800	3.53	4140	72,500	4.82
1880	159,600	0.995	2360	127,100	1.568	2960	101,300	2.47	3560	84,300	3.57	4160	72,100	4.87
1890	158,700	1.005	2380	126,000	1.594	2980	100,700	2.50	3580	83,800	3.61	4180	71,800	4.92

Table Showing Relation of Natural Wave Length, Frequency, and Inductance Capacity Product—*Continued.*

Meters	n	L×C	Meters	n	L×C	Meters	n	L×C	Meters	n	L×C	Meters	n	L×C
4200	71,500	4.96	4800	62,500	6.49	6000	50,000	10.13	7500	40,000	15.83	9000	33,300	22.8
4220	71,100	5.01	4820	62,300	6.54	6050	49,600	10.30	7550	39,700	16.04	9050	33,100	23.1
4240	70,800	5.06	4840	62,000	6.59	6100	49,200	10.47	7600	39,500	16.26	9100	33,000	23.3
4260	70,400	5.11	4860	61,800	6.65	6150	48,800	10.65	7650	39,200	16.47	9150	32,800	23.6
4280	70,100	5.16	4880	61,500	6.70	6200	48,400	10.82	7700	39,000	16.69	9200	32,600	23.8
4300	69,800	5.20	4900	61,200	6.76	6250	48,000	11.00	7750	38,700	16.90	9250	32,400	24.1
4320	69,500	5.25	4920	61,000	6.81	6300	47,600	11.17	7800	38,500	17.12	9300	32,300	24.3
4340	69,100	5.30	4940	60,800	6.87	6350	47,200	11.35	7850	38,200	17.34	9350	32,100	24.6
4360	68,800	5.35	4960	60,500	6.92	6400	46,900	11.53	7900	38,000	17.56	9400	31,900	24.9
4380	68,500	5.40	4980	60,300	6.98	6450	46,500	11.71	7950	37,700	17.79	9450	31,700	25.1
4400	68,200	5.45	5000	60,000	7.04	6500	46,200	11.89	8000	37,500	18.01	9500	31,600	25.4
4420	67,900	5.50	5050	59,400	7.18	6550	45,800	12.08	8050	37,300	18.24	9550	31,400	25.7
4440	67,600	5.55	5100	58,800	7.32	6600	45,500	12.26	8100	37,000	18.47	9600	31,300	25.9
4460	67,300	5.60	5150	58,300	7.47	6650	45,100	12.45	8150	36,800	18.70	9650	31,100	26.2
4480	67,000	5.65	5200	57,700	7.61	6700	44,800	12.64	8200	36,600	18,93	9700	30,900	26.5
4500	66,700	5.70	5250	57,200	7.76	6750	44,400	12.83	8250	36,400	19.16	9750	30,800	26.8
4520	66,400	5.75	5300	56,600	7.91	6800	44,100	13.02	8300	36,100	19.39	9800	30,600	27.0
4540	66,100	5.80	5350	56,100	8.06	6850	43,800	13.21	8350	35,900	19.62	9850	30,500	27.3
4560	65,800	5.85	5400	55,600	8.21	6900	43,500	13.40	8400	35,700	19.86	9900	30,300	27.6
4580	65,500	5.90	5450	55,100	8.36	6950	43,200	13.60	8450	35,500	20.1	9950	30,200	27.9
4600	65,200	5.96	5500	54,600	8.52	7000	42,900	13.79	8500	35,300	20.3	10000	30,000	28.2
4620	65,000	6.01	5550	54,100	8.67	7050	42,600	13.99	8550	35,100	20.6	10100	29,700	28.7
4640	64,700	6.06	5600	53,600	8.83	7100	42,300	14.19	8600	34,900	20.8	10200	29,400	29.3
4660	64,400	6.11	5650	53,100	8.99	7150	42,000	14.39	8650	34,700	21.1	10300	29,100	29.9
4680	64,100	6.17	5700	52,700	9.15	7200	41,700	14.59	8700	34,500	21.3	10400	28,800	30.4
4700	63,900	6.22	5750	52,200	9.31	7250	41,400	14.79	8750	34,300	21.6	10500	28,600	31.0
4720	63,600	6.27	5800	51,700	9.47	7300	41,100	15.00	8800	34,100	21.8	10600	28,300	31.6
4740	63,300	6.32	5850	51,300	9.63	7350	40,800	15.21	8850	33,900	22.0	10700	28,000	32.2
4760	63,000	6.38	5900	50,900	9.80	7400	40,500	15.41	8900	33,700	22.3	10800	27,800	32.8
4780	62,800	6.43	5950	50,400	9.96	7450	40,300	15.62	8950	33,500	22.5	10900	27,500	33.4

Table Showing Relation of Natural Wave Length, Frequency, and Inductance Capacity Product—*Continued.*

Meters	n	L×C	Meters	n	L×C	Meters	n	L×C	Meters	n	L×C	Meters	n	L×C
11000	27,300	34.1	14000	21,400	55.2	17000	17,640	81.3	20000	15,000	112.6	26000	11,540	190.3
11100	27,000	34.7	14100	21,300	56.0	17100	17,540	82.3	20200	14,850	114.8	26200	11,450	193.2
11200	26,800	35.3	14200	21,100	56.8	17200	17,440	83.3	20400	14,710	117.1	26400	11,360	196.2
11300	26,500	35.9	14300	21,000	57.6	17300	17,340	84.2	20600	14,560	119.4	26600	11,280	199.1
11400	26,300	36.6	14400	20,800	58.4	17400	17,240	85.2	20800	14,420	121.8	26800	11,190	202.
11500	26,100	37.2	14500	20,700	59.2	17500	17,140	86.2	21000	14,290	124.1	27000	11,110	205.
11600	25,900	37.9	14600	20,600	60.0	17600	17,050	87.2	21200	14,150	126.5	27200	11,030	208.
11700	25,600	38.5	14700	20,400	60.8	17700	16,950	88.2	21400	14,020	128.9	27400	10,950	211.
11800	25,400	39.2	14800	20,300	61.6	17800	16,850	89.2	21600	13,890	131.3	27600	10,870	214.
11900	25,200	39.9	14900	20,100	62.5	17900	16,760	90.2	21800	13,760	133.8	27800	10,790	218.
12000	25,000	40.5	15000	20,000	63.3	18000	16,670	91.2	22000	13,640	136.2	28000	10,710	221.
12100	24,800	41.2	15100	19,870	64.2	18100	16,570	92.2	22200	13,510	138.7	28200	10,640	224.
12200	24,600	41.9	15200	19,740	65.0	18200	16,480	93.2	22400	13,390	141.2	28400	10,560	227.
12300	24,400	42.6	15300	19,610	65.9	18300	16,390	94.3	22600	13,270	143.8	28600	10,490	230.
12400	24,200	43.3	15400	19,480	66.7	18400	16,300	95.3	22800	13,160	146.3	28800	10,420	233.
12500	24,000	44.0	15500	19,350	67.6	18500	16,220	96.3	23000	13,040	148.9	29000	10,340	237.
12600	23,800	44.7	15600	19,230	68.5	18600	16,130	97.4	23200	12,930	151.5	29200	10,270	240.
12700	23,600	45.4	15700	19,110	69.4	18700	16,040	98.4	23400	12,820	154.1	29400	10,200	243.
12800	23,400	46.1	15800	18,990	70.3	18800	15,960	99.5	23600	12,710	156.8	29600	10,130	247.
12900	23,300	46.8	15900	18,870	71.2	18900	15,870	100.5	23800	12,600	159.4	29800	10,070	250.
13000	23,100	47.6	16000	18,750	72.1	19000	15,790	101.5	24000	12,500	162.1	30000	10,000	253.
13100	22,900	48.3	16100	18,630	73.0	19100	15,710	102.6	24200	12,400	154.8	31000	9,680	270.
13200	22,700	49.0	16200	18,510	73.9	19200	15,630	103.7	24400	12,290	167.6	32000	9,380	288.
13300	22,600	49.8	16300	18,400	74.8	19300	15,540	104.8	24600	12,190	170.3	33000	9,090	306.
13400	22,400	50.5	16400	18,290	75.7	19400	15,460	105.9	24800	12,100	173.1	34000	8,830	325.
13500	22,200	51.3	16500	18,180	76.6	19500	15,380	107.0	25000	12,000	175.9	35000	8,570	345.
13600	22,100	52.1	16600	18,070	77.6	19600	15,310	108.1	25200	11,900	178.7	36000	8,340	365.
13700	21,900	52.8	16700	17,960	78.5	19700	15,230	109.2	25400	11,810	181.6	37000	8,110	385.
13800	21,700	53.6	16800	17,850	79.4	19800	15,150	110.3	25600	11,720	184.5	38000	7,900	406.
13900	21,600	54.4	16900	17,740	80.4	19900	15,080	111.4	25800	11,630	187.4	39000	7,690	428.

452. In measuring the inductance of a closed oscillatory circuit, say of a spark transmitter, the procedure is as follows: With the capacity known, the wave lengths of the closed-circuit inductance are measured, turn by turn, with the wavemeter at resonance with this circuit. With a spark transmitter, the antenna should be disconnected from the antenna inductance coil while this measurement is taking place, and the transformer of the set may be used for energizing the circuit, but low power should be used, so as to avoid damaging the condensers. A simple curve is made, showing the wave lengths obtained, as indicated on the dial of the wavemeter, as the clip is moved from one turn to the next across the inductance coil. As the capacity of the condenser, or bank of condensers, is known, the inductance of the coil may be determined by picking out the LC for each wave length, as shown in the LC table, and dividing this number by the known capacity of the circuit.

$$L = \frac{LC}{C} \text{ and } C = \frac{LC}{L}$$

Turns	W.L.	LC	$\frac{LC}{C}$ = L
1	200	.01113	.93
2	375	.0395	3.3
3	525	.0776	6.5
4	650	.119	9.9
5	750	.158	13.1
6	825	.192	16.0
7	900	.228	19.0
8	975	.268	22.0

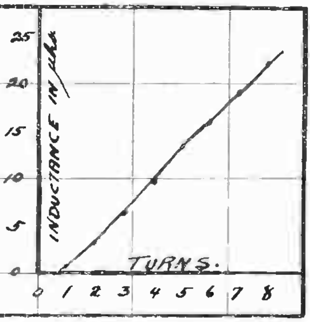


Fig. 576. Inductance Curve of the Primary-Oscillatory Circuit of a Transmitter.

It is then a simple matter to make a curve of the inductance of the circuit obtained for the various turns of the coil.

The wavemeter is used for determining the results of connecting a condenser or loading inductance in the antenna system. After the natural wave length of the antenna system has been determined, a series condenser may be added, and the total capacity determined by the following formula:

$$C = \frac{\lambda_1^2 - \lambda_2^2}{\lambda_2^2} \times C_1$$

In this, C = The total capacity of the antenna system under measurement

λ_1 = The fundamental wave length of the antenna as found by the first wavemeter reading

λ_2 = The wave length of the antenna system after the series condenser has been added, as determined by the wavemeter

C_1 = The known capacity of the series condenser.

The inductance of the antenna may be found in the same way by the following rule:

$$L = \frac{\lambda_1^2}{\lambda_2^2 - \lambda_1^2} \times l$$

Where L = The total inductance of the antenna system in centimeters

λ_1 = The fundamental wave length of the antenna

λ_2 = The wave length of the antenna with the loading coil added

l = The known inductance of the loading coil.

453. For calibrating a receiving set to a desired wave length, or range of wave lengths, to be marked on the dials, the wavemeter calibrated inductance and capacity is used in connection with a buzzer or other type of circuit-driver producing damped or undamped vibrations, according to the type of receiver to be calibrated. The circuit-driver is inductively coupled to a single turn in the antenna ground wire, while the receiving set is coupled to the antenna. The antenna and secondary circuit of the receiving tuner are then adjusted until a clearly defined maximum of volume is heard in the receiving telephones at the particular wave length at which the driver is set.

It is found that the wave length of the antenna and the receiver tuning circuit are both affected by the coupling of the two together. Hence the most accurate calibration of the receiving set must include the antenna system, as well as the set proper. This is on account of the mutual inductance caused by the induction between the two circuits. This produces a frequency different from that which is natural to either circuit when excited independently, so that the mutual inductance must be considered as a part of the total in each circuit. This effect is usually referred to as the *coupling coefficient,* and in formulæ it is represented by the letter K. The fundamental rule for this is as follows:

$$K = \frac{M}{\sqrt{L_1 L_2}}$$

M = the mutual inductance.
L_1 = the inductance of the primary circuit alone.
L_2 = the inductance of the secondary circuit alone.

When applied to wave lengths, we have the following standard rule:

$$K = \frac{\lambda_2^2 - \lambda_1^2}{\lambda_2^2 + \lambda_1^2}$$

with λ_1 standing for the shorter wave length and λ_2 for the longer. These rules apply to all coupled oscillatory circuits, either receiving or transmitting. In all such circuits two frequencies are present, which depend upon the coupling and the decrement of the circuits. The wave lengths of these two circuits will be found to correspond to the fol-

$$\lambda_1 = \lambda \sqrt{1 - K_1}$$

$$\lambda_2 = \lambda \sqrt{1 + K_1}$$

in which λ is the wave length to which the circuits are tuned independently before being coupled together. Where λ represents the wave length reading obtained from the coupled circuits and K_1 is as follows, in which d_1 signifies the decrement of one of the circuits and d_2 the decrement of the other circuit coupled to it:

$$K_1 = \sqrt{K^2 - \left(\frac{d_1 - d_2}{2\pi}\right)^2}$$

The reactance of the mutual inductance is such that the flow of current in each circuit is different from that obtained when this factor is absent. With inductively coupled circuits in which the primary and secondary are independently adjusted to resonance with an impressed frequency,

$$\omega = \frac{1}{\sqrt{L_1 C_1}} = \frac{1}{\sqrt{L_2 C_2}}$$

And with R_1 standing for the resistance of the primary and R_2 for that of the secondary, and M in henries,

$$I_1 = \frac{E\ R}{R_1\ R_2 + \omega^2\ M^2}$$

$$I_2 = \frac{E\ \omega\ M}{R_1\ R_2 + \omega^2\ M^2}$$

Also, with the primary frequency represented by N_1, and n the spark-discharge frequency of the closed circuit of a spark transmitter, the effective current indicated by a thermo-coupled ammeter in the secondary, or antenna circuit, is as follows:

$$I_2\ \text{eff.} = E_1 \left[n \frac{1}{64\ \pi^2\ N_1^3\ L_2^2} \frac{d_1 + d_2}{d_1\ d_2} \frac{1}{\left(1 - \frac{N_2}{N_1}\right)^2 + \left(\frac{d_1 + d_2}{2\pi}\right)^2} \right]^{1/2}$$

At resonance $N_1 = N_2$

$$I_2\ \text{eff.} = E_1 \left[n \frac{1}{16\ N_1^3\ L_2^2} \frac{1}{d_1\ d_2\ (d_1 + d_2)} \right]^{1/2}$$

With primary undamped and $N_1 = N_2$

$$I_2\ \text{eff.} = E_1 \left[\frac{1}{8\ N_1^2\ L_2^2} \frac{1}{d_2^2} \right]^{1/2}$$

454. The Bridge method is most frequently used for the *measurement of capacity,* as, for instance, of a condenser. This is usually referred to as a capacity bridge. A buzzer is usually inductively coupled to the bridge, as shown in figure 577 at A, or some other source of alternating current may be used, if desired. R_1 and R_2 are standard resistance boxes. C_1 represents the known capacity, and C_2 the unknown capacity. The resistance used is generally from 1,000 to 2,000 ohms, and the capacity of C_1 is usually .001 microfarad. If a calibration curve of this known capacity is available, the measurement of C_2 may be accomplished with a fair degree of accuracy. Otherwise it can be only roughly

approximate. The capacity of C_1 is varied until, at a particular setting, the sound in the telephones is reduced to a minimum, at which point a balance between the two capacities has been secured. This assumes that the values of R_1 and R_2 are identical. Otherwise

$$\frac{R_1}{R_2} = \frac{C_1}{C_2}$$

For instance, if R_1 is 1,000 ohms and R_2 is 5,000 ohms,

$$\frac{1000}{5000} = \frac{.0005}{C_2} = \frac{.0005}{.2} = .00025,$$ which is the capacity of C_2.

Large resistances are employed when the capacities are small, and vice versa. If a variable condenser is to be calibrated by this method, it should be measured at ten or more dial settings, and a curve made, showing capacity obtained at each setting. In the best condensers this curve is practically a straight line.

The following formula for determining the capacity of a

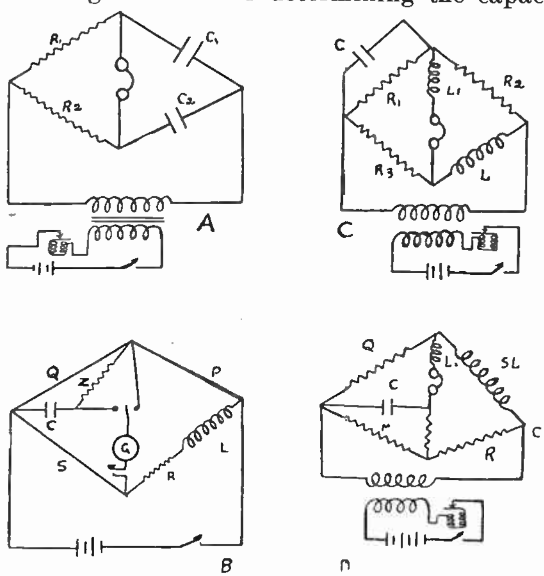


Fig. 577. Methods of Measuring Capacity and Inductance by Adaptations of Wheatstone Bridge.

variable condenser with semi-circular plates is from the *Circular of the Bureau of Standards, No. 74.*

$$C = 0.1390\ K \frac{(N-1)\quad (r1^2 - r2^2)}{t}$$

N = total number of plates
r1 = outside radius of the plates
r2 = inner radius of plates
t = thickness of dielectric
K = dielectric constant.

455. The measurement of inductance by the bridge method is indicated at B, in figure 577. This is known as the Anderson method.

R = the resistance of the inductance coil
L = the inductance of the coil
Z = a plug resistance box

P, S and Q have a known resistance.

$$\frac{P}{Q} = \frac{S}{R} \text{ and } R = \frac{SQ}{P}$$

The balance is first established for direct current, at which point the galvanometer will show no deflection and low powered alternating current, or buzzer interrupted, substituted.

Maxwell's method of measuring inductance is shown at C, in figure 577. In this the inductance of the coil is compared with the capacity of a variable condenser. The bridge is first balanced for direct current, and then a buzzer substituted. The capacity of C is varied until the sound in the telephone is minimum. Then, with R_4 representing the resistance of L,

$$L = C\ R_2\ R_3 = C\ R_1\ R_4$$

This method is most suitable for small coils with a small amount of inductance.

At D, the balance is obtained by adjusting the resistance r until the minimum sound is heard. The resistance of the coil SL is first determined by the usual resistance bridge method. Then the inductance of L is as follows:

$$L = C\ (r\ (Q + S) + R\ Q)$$

The counter emf. set up in the coil, in a direction opposite to the counter emf. of the condenser causes current to flow through the telephones. When r is adjusted so that these are equal, the sound in the telephone will be at the minimum.

A formula which gives the approximate inductance of a single layer coil is Nagaoka's:

$$L = 0.03948 \frac{n^2 r^2}{l} K$$

In this, n = number of turns
r = radius of the coil
l = length of the coil
K = elongation factor.

With the lengths in centimeters the result will be in microhenries. Quoting from Dr. Dellinger, of the Bureau of Standards, in *Radio Lefax:* "The nature of the elongation factor is explained as follows:

$$L = 0.03948 \frac{n^2 r^2}{l}$$

This formula assumes that when a current is passed through the coil and a magnetic field set up, all the magnetic lines of force pass through the coil from one end to the other without any of them escaping to the outside between the turns of the coil. This leakage causes a diminution of the inductance of the winding, which becomes quite appreciable as the diameter of the coil increases in proportion to the length. To correct for this leakage, we resort to multiplication by the elongation factor, which is a function of the ratio d/1. Nagaoka has computed values of K, which are given in the table on page 676.

In using the accompanying Nagaoka table of solutions of the formula given just above, suppose it is desired to determine the inductance of a coil 4 centimeters in diameter and 6 centimeters long, composed of No. 28 double silk-covered copper wire. It is shown in the table to have an inductance of approximately 76 microhenries. On the other hand, suppose it is desired to prepare a coil, composed of No. 20 enameled wire, to have an inductance of about 500 microhenries. We find in the table that the coil should be 13½ centimeters long if it is 6 centimeters in diameter, 8¾ centimeters long if its diameter is 8 centimeters, 7 centimeters long if its diameter is 10 centimeters, etc.

The inductance, when the coil is connected in the circuit, is, of course, affected by the distributed capacity and the frequency of the current. The capacity reactance increases with a decrease in frequency and a decrease in capacity, and vice versa. The following formula can be used for this calculation:

$$X_c = \frac{159.3}{fC}$$

f = frequency in kilocycles
C = capacity in microfarads
X_c = capacity reactance in ohms.

According to Dr. Dellinger, "The effect of distributed capacity is to cause an increase in the inductance of the coil. The capacity itself is not calculable directly, but its value may be determined by applying these formulas to resonance

NAGAOKA TABLE OF VALUES OF K IN CALCULATION OF INDUCTANCE OF SINGLE LAYER COILS

Diam./Length	K	Diam./Length	K	Diam./Length	K	Diam./Length	K	Diam./Length	K
0.00	1.0000	2.00	0.5255	4.00	0.3654	8.00	0.2366	30.0	0.0910
0.10	0.9588	2.10	.5137	4.20	.3551	8.50	.2272	35.0	.0808
0.20	.9201	2.20	.5025	4.40	.3455	9.00	.2185	40.0	.0728
0.30	.8838	2.30	.4918	4.60	.3364	9.50	.2106	45.0	.0664
0.40	.8490	2.40	.4816	4.80	.3279	10.00	.2033	50.0	.0611
0.50	0.8181	2.50	0.4719	5.00	0.3198	10.0	0.2033	60.0	0.0528
0.60	.7885	2.60	.4626	5.20	.3122	11.0	.1903	70.0	.0467
0.70	.7609	2.70	.4537	5.40	.3050	12.0	.1790	80.0	.0419
0.80	.7351	2.80	.4452	5.60	.2981	13.0	.1692	90.0	.0381
0.90	.7110	2.90	.4370	5.80	.2916	14.0	.1605	100.0	.0350
1.00	0.6884	3.00	0.4292	6.00	0.2854	15.0	0.1527	......	......
1.10	.6673	3.10	.4217	6.20	.2795	16.0	.1457	......	......
1.20	.6475	3.20	.4145	6.40	.2739	17.0	.1394	......	......
1.30	.6290	3.30	.4075	6.60	.2685	18.0	.1336	......	......
1.40	.6115	3.40	.4008	6.80	.2633	19.0	.1284	......	......
1.50	0.5950	3.50	0.3944	7.00	0.2584	20.0	0.1236	......	......
1.60	.5795	3.60	.3882	7.20	.2537	22.0	.1151	......	......
1.70	.5649	3.70	.3822	7.40	.2491	24.0	.1078	......	......
1.80	.5511	3.80	.3764	7.60	.2448	26.0	.1015	......	......
1.90	.5379	3.90	.3708	7.80	.2406	28.0	.0959	......	......

SELF-INDUCTANCE OF SINGLE-LAYER COILS (MICROHENRIES)

Wire Size and Insulation				Diam. Mils	Turns per Inch	Turns per cm.	d = 4 (cms.)						d = 6 (cms.)						d = 8 (cms.)					
Cotton		Silk					Length (cms.)						Length (cms.)						Length (cms.)					
Double	Single	Double	Single) (enamel				4	6	8	10	12	14	4	6	8	10	12	14	4	6	8	10	12	14
20	....	....	....	42.161	23.72	9.33	38	63	90	117	149	174	73	127	185	244	304	364	115	206	302	403	507	607
....	20	....	....	37.861	26.41	10.39	45	76	108	139	172	204	88	152	221	291	364	435	138	246	361	482	607	725
....	....	20	....	36.161	27.66	10.89	50	88	123	159	196	234	100	174	253	333	415	497	157	281	413	552	695	830
22	....	....	....	35.547	28.13	11.08	53	90	127	165	203	241	104	181	262	342	428	514	163	291	427	570	717	857
....	....	....	20	34.261	29.18	11.49	57	96	136	177	218	260	112	196	281	370	460	552	175	312	457	612	770	922
....	22	....	....	31.247	31.40	12.36	66	111	157	205	251	300	129	224	325	427	531	637	202	381	529	707	890	1065
24	....	....	....	30.300	33.01	13.00	73	123	174	226	279	332	143	248	359	474	590	707	225	400	586	784	987	1180
....	....	22	....	29.547	33.85	13.33	77	129	183	238	293	448	150	260	377	497	617	740	235	420	616	822	1032	1232
....	....	....	22	27.647	36.16	14.24	88	148	209	272	334	399	172	298	431	569	705	847	269	480	702	941	1181	1415
26	....	....	....	26.140	38.25	15.05	98	165	234	304	374	446	192	332	483	636	790	950	301	535	787	1055	1320	1582
....	24	....	....	26.000	38.46	15.12	99	166	235	305	376	447	193	335	486	644	796	952	302	545	792	1057	1332	1590
....	....	24	....	24.300	41.15	16.17	114	191	271	351	431	500	221	384	559	735	912	1092	347	619	912	1215	1527	1822
28	....	....	....	22.841	43.78	17.23	129	217	306	399	489	582	250	435	632	832	1032	1245	392	701	1057	1377	1731	2071
....	....	....	24	22.401	44.65	17.55	134	225	318	412	507	605	260	452	656	867	1071	1290	408	727	1100	1429	1750	2150
....	26	....	....	21.840	45.78	18.01	140	236	334	434	535	636	273	475	690	907	1130	1355	429	765	1156	1504	1892	2257
30	....	....	....	20.225	49.45	19.48	165	277	392	510	627	747	321	557	810	1066	1325	1592	502	897	1356	1762	2225	2652
....	....	26	....	20.140	49.66	19.52	166	279	394	512	631	751	323	560	812	1070	1331	1595	506	902	1362	1770	2231	2667
....	28	....	....	18.541	53.94	21.25	196	329	467	601	742	885	380	661	935	1262	1570	1882	596	1066	1567	2087	2635	3137
....	....	....	26	18.240	54.83	21.55	202	339	430	622	767	912	393	682	990	1305	1621	1944	615	1100	1659	2156	2715	3237
....	....	28	....	16.841	59.37	23.40	237	398	564	731	900	1057	461	800	1162	1530	1900	1981	722	1287	1950	2530	3182	3805
....	30	....	....	15.925	62.81	24.70	265	445	630	817	1006	1200	515	895	1272	1707	2127	2550	807	1442	2180	2830	3562	4257
....	....	....	28	14.941	66.92	26.35	297	500	707	932	1130	1346	579	1006	1457	1947	2385	2865	907	1620	2445	3225	4000	4747
....	....	30	....	14.225	70.33	27.70	334	560	792	1015	1265	1505	647	1125	1632	2125	2670	3200	1017	1812	2737	3555	4475	5337
....	....	....	30	12.325	81.17	31.09	444	744	1052	1367	1680	2000	862	1495	2170	2857	3550	4250	1355	2410	3637	4725	4950	7100

SELF-INDUCTANCE OF SINGLE-LAYER COILS (MICROHENRIES)

Wire Size and Insulation				Diam. Mils	Turns per Inch	Turns per cm.	d=10 (cms.)						d=12 (cms.)						d=14 (cms.)					
Cotton		Silk					Length (cms.)						Length (cms.)						Length (cms.)					
Double	Single	Double	Single				4	6	8	10	12	14	4	6	8	10	12	14	4	6	8	10	12	14
20	....	....	....	42.161	23.72	9.33	162	273	412	590	750	910	212	389	587	800	1020	1250	266	494	750	1030	1319	1625
....	20	....	....	37.861	26.41	10.39	194	296	492	707	896	1087	254	465	702	956	1220	1492	318	589	899	1230	1580	1940
....	....	20	....	36.161	27.66	10.89	221	339	564	810	1025	1245	290	532	805	1095	1397	1707	362	673	1030	1407	1806	2220
22	....	....	....	35.547	28.13	11.08	228	351	587	837	1057	1284	300	551	831	1131	1442	1762	375	697	1067	1455	1865	2292
....	....	....	20	34.261	29.18	11.49	243	625	897	1137	1482	1382	322	592	891	1215	1547	1897	401	750	1142	1560	2002	2467
....	22	....	....	31.247	31.40	12.36	284	435	722	1035	1312	1595	372	682	1031	1405	1790	2192	466	865	1319	1805	2312	2845
24	....	....	....	30.400	33.01	13.00	315	482	800	1150	1455	1770	413	757	1142	1555	1982	2430	516	960	1457	2000	2562	3162
....	....	22	....	29.547	33.85	13.33	330	506	842	1206	1527	1855	433	795	1200	1632	2082	2535	442	1006	1532	2100	2687	3305
....	....	....	22	27.647	36.16	14.24	378	579	960	1380	1742	2122	496	910	1370	1867	2375	2912	621	1155	1750	2400	3070	3787
26	....	....	....	26.140	38.25	15.05	422	646	1075	1545	1950	2377	555	1015	1532	2087	2660	3262	692	1285	1962	2682	3437	4237
....	24	....	....	26.000	38.46	15.12	425	651	1081	1550	1965	2382	557	1020	1542	2095	2680	3275	697	1295	1972	2695	3462	4250
....	....	24	....	24.300	41.15	16.17	489	745	1245	1782	2255	2732	640	1170	1775	2412	3070	3650	802	1482	2267	3100	3970	4750
28	....	....	....	22.841	43.78	17.23	551	845	1407	2020	2555	3107	722	1329	2007	2732	3480	4255	905	1681	2565	3512	4500	5525
....	....	....	24	22.401	44.65	17.55	572	879	1459	2095	2650	3227	762	1380	2082	2830	3612	4425	940	1746	2562	3645	4662	5750
....	26	....	....	21.840	45.78	18.01	602	922	1534	2205	2787	3387	790	1446	2187	2980	3800	4650	987	1835	2800	3832	4787	6050
30	....	....	....	20.225	49.45	19.48	707	1082	1804	2585	3275	3982	927	1700	2565	3500	4462	5462	1159	2155	3287	4500	5775	7100
....	....	26	....	20.140	49.66	19.52	711	1087	1812	2595	3287	4000	932	1707	2580	3525	4487	5475	1167	2165	3305	4520	5787	7125
....	28	....	....	18.541	53.94	21.25	837	1282	2082	3012	3875	4712	1097	2017	2962	4145	5225	6462	1375	2555	3900	5325	6825	8400
....	....	....	26	18.240	54.83	21.55	865	1325	2205	3162	4000	4862	1132	2081	3057	4275	5462	6675	1420	2637	4017	5500	7062	8675
....	....	28	....	16.841	59.37	23.40	1015	1555	2587	3707	4695	5712	1330	2440	3687	5012	6400	7825	1665	3090	4712	6450	8275	10175
....	30	....	....	15.925	62.81	24.70	1137	1737	2895	4150	5250	6637	1487	2657	4125	5612	7162	8762	1862	3462	5275	7225	9250	11412
....	....	....	28	14.941	66.92	26.35	1275	1955	3250	4725	5900	7175	1670	3067	4662	6400	8025	9850	2091	3887	5925	8225	10375	12800
....	....	30	....	14.225	70.33	27.70	1429	2187	3637	5212	6600	8125	1875	3430	5175	7062	9000	10225	2342	4350	6625	9075	11625	14300
....	....	....	30	12.325	81.17	31.90	1900	2905	4835	6925	8775	10662	2490	4562	6887	9375	11925	14600	3120	5775	8812	12062	15437	19000

methods of measurement. The inductance of the coil is decreased by skin effect and increased by capacity. The two tend to neutralize each other and, in general, Nagaoka's formula, and the table give us as good values of self-inductance as can be obtained. If a coil be placed in a circuit with an E. M. F. in series, the case is one of parallel resonance and the apparent inductance of the coil is given by

$$La = \frac{L(1 - \omega^2 LC)}{(1 - \omega^2 LC)^2 - \omega^2 R^2 C^2} - \frac{R^2 C}{(1 - \omega^2 LC)^2 - \omega^2 R^2 C^2}$$

in which L is in henries, C in farads and R in ohms.

456. Capacity and inductance may be measured by the wavemeter, with a calibrated capacity or inductance or both. With a wave length calibration curve of the wavemeter, and a known capacity, the unknown inductance may be substituted in the wavemeter circuit for the regular wavemeter coil. Another calibrated wavemeter is then used as a sender, and the two meters adjusted to resonance.

As the wave length of a concentrated inductance is

$$\lambda = 59.6 \sqrt{LC}$$

$$L = \frac{\lambda^2}{59.6^2 C}$$

with C in microfarads and L in centimeters.

The capacity of a condenser is found by using a known inductance of which a calibrated curve is on hand, with a condenser of unknown capacity. This is then calibrated to resonance with a wavemeter, and

$$C = \frac{\lambda^2}{59.6^2 L}.$$

457. A *wavemeter* may be *calibrated* by tuning in another wavemeter equipped as a circuit driver, and making a curve of condenser settings for different wave lengths and with different inductance coils. The results of this may be checked by use of a regenerative receiver, with the wavemeter excited by a buzzer or oscillator and inductively coupled to the antenna. The receiver is used to tune in a transmitter of known wave length, preferably the Bureau of Standards, and tuned until the oscillation whistle is not heard. The wavemeter is then tuned in on the receiver with-

out changing the adjustment of the latter, and a record made of wavemeter condenser setting. A curve may be made of condenser settings for different stations. With a 43-plate condenser and a coil of only a few turns of wire, a curve of wave length squared plotted against condenser dial settings should be a straight line.

A quartz-crystal oscillator is an accurate and labor-saving apparatus to use in calibrating a wavemeter, as well as for checking on the frequency of a transmitter directly. An auxiliary generator is used with this. The vacuum-tube circuit in the crystal-oscillator apparatus gives several harmonics for each fundamental frequency. The auxiliary generator, which is variable, can be adjusted for any frequency and also gives harmonics. The overlapping of the

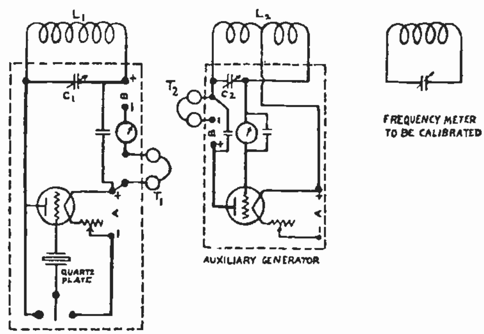


Fig. 578. Method of Calibrating a Wavemeter With a Quartz-Crystal Oscillator.
(Bureau of Standards.)

frequency of the piezo oscillator and the frequency of the auxiliary generator produces an audible heterodyne beat which can be heard in the head phones of either circuit. By tuning this beat completely out, it is determined that the auxiliary generator is oscillating at the same frequency as that of the piezo oscillator. This frequency can then be transferred from the auxiliary generator to the frequency meter, or wavemeter. The harmonics produced by both the auxiliary generator and piezo oscillator make it possible to obtain a great many points.*

*Bureau of Standards *Circular Letter LC*-186 gives detailed specifications and blueprint for making a piezo frequency standard. *Circular Letter No.* 187 gives directions for making auxiliary generator. *Circular Letter* 183 is directions for use of these apparatus. Letters obtainable free at Bureau of Standards, Washington, D. C.

458. *To measure the wave length of a distant transmitting station,* of which the wave length is not known, the station is tuned in at maximum volume on the receiving set. The wavemeter, employing the circuit-driver, is then loosely coupled to the receiver and adjusted to resonance to the latter, without altering the receiver adjustments. This will show the wave at which the receiver was adjusted for tuning in the distant station, calibrating the receiver to this wave length and determining the wave length of the distant station at the same time.

What is known as the "resonance click" method of using the wavemeter is popular among amateurs. In this, the inductance coil and condenser part of the wavemeter only are used. The meter is brought close to an oscillating vacuum-tube receiving set. When near enough to the receiver, and at resonance with the receiver, the wavemeter circuit will absorb enough of the energy set up by the oscillations in the receiver to stop its oscillating, and this will cause a click in the receiver telephones.

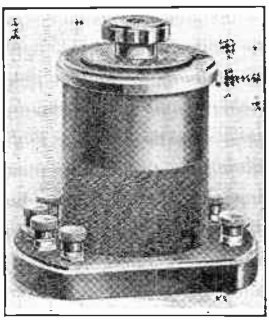


Fig. 579. Separate Calibrated Inductance and Capacity for Use as Circuit-Driver Receiving Wavemeter, or Filter, According to Connections. (Connecticut Telephone & Electric Company.)

A calibrated inductance and capacity may be constructed as a separate unit, to be connected to various circuits for different purposes.

459. The wavemeter is also used in measurements pertaining to *antenna resistance,* radiated power, etc. The *resistance of an antenna* is an important factor in the efficiency of a transmitter. Many various effects produce the total opposition to current, or loss, due to apparent resistance, and it is difficult to separate them in actual measurements. So it is customary to determine the losses in an antenna system by a measurement of the *effective resistance.*

The apparent resistance of an antenna is due to three types of losses: (1) The heat caused by the ohmic resistance of the wire; (2) dielectric absorption, and (3) radiation. The latter is not actually a resistance, and as such does not exist, but as a factor including dissipation of current it can be measured. It is also possible to have losses of energy due to brush discharge at extremely high voltages, and through imperfect insulators.

The actual ohmic resistance losses occur in the wire, ground and connections of the antenna system. The power lost due to this cause is equal to I^2 R. The losses due to dielectric absorption are caused by the presence of trees, buildings, iron, etc., in the field of the antenna. These may produce losses in different ways. The iron may absorb a portion of the energy. The trees may conduct energy to the ground. Buildings, wooden shacks and poles, or shrubbery may produce capacity effects absorbing a small portion of the energy. Insulators of poor quality may also absorb energy.

The practical operator usually depends upon the antenna ammeter as an indication of the radiation, and indirectly of the antenna resistance. However, this is only roughly approximate. It is possible to have the ammeter show a good reading and yet to be radiating much less of the energy thus represented than might be supposed. A measurement of the power radiated is the most definite indication of the total impedence of a transmitting antenna; and the most practical method of accomplishing this is to tune in the transmitting station on a neighboring receiver and make a memorandum of the effect of every change as it is made in the transmitting system.

It is found that the power radiated is greatest when the antenna is operated at some particular frequency, or that certain frequencies have a greater reactance than others, for the antenna system designed in some particular manner. Quoting from *Radio Instruments and Measurements, Circular of the Bureau of Standards, No. 74:* "The amount of power radiated depends upon the form of the antenna, is proportional to the square of the current flowing at the current antinode of the antenna, and inversely proportional to the square of the wave length of the oscillation. Since the power is proportional to the square of the current, it may be considered to be caused by an equivalent or effective resistance, which is called the radiation resistance of the antenna. Thus, the radiation resistance of an antenna is that resistance which, if inserted at the antinode of current in the antenna, would dissipate the same power as that radiated by the antenna. The radiation resistance varies with the wave length in the same way as the radiated power; i. e., inversely as the square of the wave length."

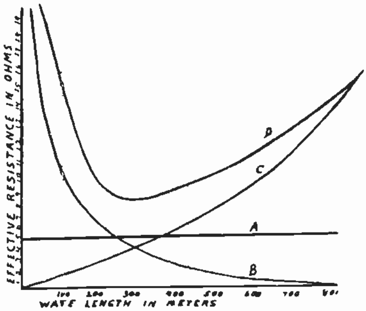


Fig. 580a. Curve of Components of Antenna Resistance.

The total resistance of an antenna is customarily represented by a curve as in figure 580a. A represents the actual d. c. resistance of the wire and connections. B shows how the radiation resistance decreases as the wave length increases, according to the skin effect of high-frequency currents. C indicates the increased capacity reactance as the longer wave lengths are used; and D the total effective resistance of the antenna system at different frequencies. When these curves are made accurately of a particular antenna they are called the *constants* of that antenna. The total resistance may be as much as 25 or 30 ohms at the fundamental wave length. For land stations about 5 ohms is the minimum resistance obtainable, and on ship stations it may be as low as 2 ohms. It requires patient work to make such a curve, determining the effective resistance on many different wave lengths, until the data in the curve is shown by comparison.

460. The *radiation resistance* should be large, in proportion to the losses due to other causes. In other words, an ideal antenna system is one in which the ohmic resistance of the wires and connections is small, where losses due to absorption are avoided, and where a large percentage of the current which appears to have been lost in the antenna system has been consumed in radiating energy. One way of *measuring the radiation resistance* is to construct a dummy antenna, consisting of the same inductance, capacity, and ohmic resistance as the actual antenna. When the current of the same frequency and voltage as that delivered to the antenna is sent through this circuit, the power lost will be considerably less than in the actual antenna system. This difference will be equal to $I^2 R_r$.

In measuring the effective resistance of an antenna, measurements of capacity and inductance are necessarily included. And as the question of resonance with the frequency of the oscillations has much to do with the current flowing, it can be seen that the determining of current and voltage in an antenna is closely related to wave length. A standard formula for the total radiation resistance of an antenna is as follows:

$$R_r = 160\,\pi^2 \left(\frac{a\ h}{\lambda m}\right)^2$$

In this a represents the form factor, which is dependent upon the current distribution along the vertical part of the antenna, and h represents the height in meters. When the distribution is uniform, a is equal to 1. For a straight wire vibrating at its fundamental frequency

$$a = \frac{2}{\pi}$$

and for a highly loaded antenna it is equal to 0.5.

The total effective antenna resistance is

$$Ra = \frac{P}{I^2}$$

and the power radiated is $P = RrI^2$ with I representing the reading of the ammeter near the base of the antenna.

$$\text{Also, } Ra = K \left(\frac{h}{\lambda}\right)^2$$

where $K = 40\ (2\pi)^2 = 1580$
and h = height in meters.
The power radiated is then,

$$1578 \frac{h^2}{\lambda^2} I^2$$

with height and wave length represented in meters, and I representing current reading at the base of the antenna.

461. The antenna ammeter, being usually located near the base of the antenna gives a reading of current which is different from that which would be obtained if it were connected higher up in the antenna system, or out on the horizontal portion. This is because the current is stronger near

the grounded end of the antenna. For instance, in figure 580b, A represents the current and voltage distribution in a simple vertical-wire antenna which is oscillating at its fundamental frequency, in which case the wave length is approximately four times the length of the wire. The voltage is zero at the base of the antenna. This is known as the nodal point of the voltage, or the voltage node. Likewise, the *current node* is at the top of the antenna. If a horizontal wire be added, the current and voltage distri-

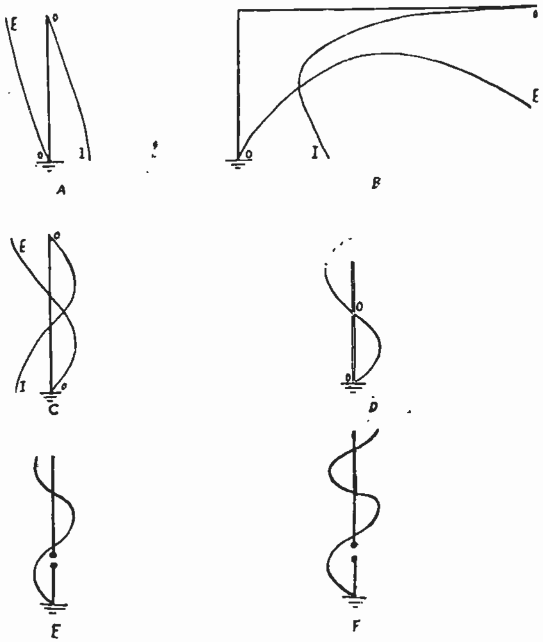


Fig. 580b. Current and Voltage Distribution in Antennae.

bution will be approximately as shown at B. The current through the vertical portion of this antenna is more nearly equal, on account of the current node being at the end of the horizontal portion. The higher the antenna and the longer the horizontal wires, the greater will be the voltage produced at the end.

These effects are quite different from any condition possible with direct current, where the current voltage distribution is affected solely by the metallic resistance in various parts of the circuit. The high-frequency currents behave in a different manner, in the antenna circuit being affected very much by the capacity between the different portions of the antenna and the ground. The nodal points, or the location on the antenna structure at which the current and voltage fall to zero and reverse their direction, depend upon the ratio of the oscillation frequency to the fundamental period of the antenna. And the reason for the voltage node being always at the base of the antenna is the combined effect of the enormous capacity of the earth and its fixed voltage, which would remain comparatively uninfluenced by the relatively feeble voltage of the antenna system.

The distribution of current and voltage in an antenna system may differ from that indicated in A or B, in figure 580b, as, for instance, in the case of harmonic oscillations, but there will always be a voltage node at the ground connection and a current node at the opposite end. The current and voltage distribution in the antenna which is oscillating at its first harmonic is shown at C. D represents simply the voltage distribution when the antenna is oscillating at its first harmonic. If the curve is continued as indicated by the dotted line it can be seen that in this case the wire is approximately three-fourths of the wave length, and the wave length is one-third of the fundamental wave length of the antenna. E and F are Fleming's illustration of a spark-gap-excited antenna vibrating respectively at its second and third harmonic.

A standard formula for arriving approximately at the position of the voltage nodes is known as the ql equation. In this,

Ex = the voltage x feet from base of antenna
Ix = current x feet from base of antenna
Lo = antenna inductance in henries
Co = antenna capacity in farads
l = length of antenna from base to tip in feet

$$Ex = A \cos (ql - qx) \cos \omega t$$

$$Ix = A \sqrt{\frac{Co}{Lo}} \sin (ql - qx) \sin \omega t$$

A = the constant depending on the amplitude of the impressed voltage and is represented by the following:

$$A = \frac{E}{\cos ql}$$

and with E standing for the voltage induced at the *base* of the antenna, and q found from the equation

$$ql = \omega \sqrt{Lo\ Co}$$

The amplitudes of current and voltage are

$$Ix = j\ A \sqrt{\frac{Co}{Lo}} \sin q\ (l - x)$$

$$Ex = A \cos q\ (l - x)$$

with j representing $\sqrt{-1}$ signifying that the current and voltage are 90° out of phase.

So the nodes and loops of current and voltage are shown to be

$$E_e = \frac{E}{\cos ql} \cos O = \frac{E}{\cos ql}$$

$$I_e = j \frac{E}{\cos ql} \sqrt{\frac{C_o}{L_o}} \sin O = O$$

$$E_o = \frac{E}{\cos ql} \cos ql = E$$

$$I_o = j \frac{E}{\cos ql} \sqrt{\frac{C_o}{L_o}} \sin ql$$

$$= j E \sqrt{\frac{C_o}{L_o}} \tan ql$$

$$X_o = -j \sqrt{\frac{L_o}{C_o}} \cot ql$$

and the reactance of the antenna to the impressed voltage,

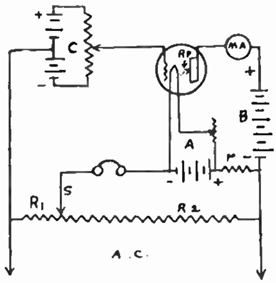
$$X_o = -j \sqrt{\frac{L_o}{C_o}} \cot ql$$

With q_o, λ_o, f_o, and ω_o standing for the fundamental frequency of an unloaded antenna, its reactance is zero, or

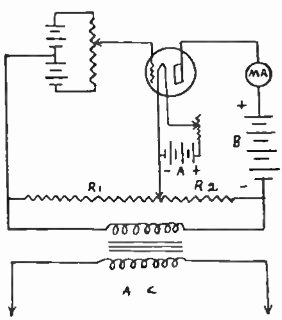
$$\cot q_o\, l = 0$$

The $\cos \theta = O$ when the angle is
$90° \pm (180°n)$ where n stands for any whole number; or

$$q\,(l - x) = (2n + 1)\frac{\pi}{2}$$



A



B

Fig. 581. Resistance Bridge Methods of Measuring Vacuum-Tube Constants.

Then $q_o\, l = \frac{\pi}{2}\, n$, with n being 0.

The positions of the voltage nodes in the antenna are then shown to be

$$\frac{x}{l} = 1 - (2n + 1)\frac{\lambda}{\lambda_o}$$

For instance, an antenna having a fundamental period of 200 meters and being caused to vibrate at a frequency producing a wave length of 45 meters would have a voltage node 32½ feet from the base and another one 77½ feet from the base.*

462. *Measurements of the constants of vacuum tubes* may be made by different methods. In a general way these may be divided into static and dynamic methods. In the static method, the filament of the tube is lighted, and a positive potential placed on the plate. A bias is then given to the grid of the tube. The grid is connected to a C battery through a

* We are indebted for the above data on the old ql formula to *Experimental Wireless and the Wireless Engineer,* London, England, September, 1924.

For further research concerning radio frequency measurements, see *Circular of the Bureau of Standards No. 74*; *The Principles of Electric Wave Telegraphy*, by John Ambrose Fleming; *Principles of Radio Communication*, by J. H. Morecroft, and *Radio Communication*, by John Mills.

For formulæ and tables for calculation of mutual and self-inductance, see *Bureau of Standards Scientific Paper, No. 169.*

potentiometer which makes it possible to vary the voltage and polarity of this bias until an adjustment has been reached which will reduce the plate current to zero, as indicated by a milliammeter in series with the plate and B battery. The filament-to-plate path of the electrons is connected so as to form one branch of a wheatstone bridge, of which the other branches are r, R_1 and R_2, the latter two being variable and consisting of sections of a slide wire resistance unit. With the bridge shunted across a source of alternating current, the slider is moved until nothing is heard in the head telephones. This indicates a balance of resistance, and the internal resistance of the tube from filament to plate is determined as follows:

$$Rp = \frac{R_2}{R_1} r$$

When this is found for various plate voltages, and plotted in a curve, we have a useful guide to the operating characteristic of the tube. This is known as the static curve of the tube. The bridge for obtaining this is shown at A in figure 581.

The dynamic method of arriving at the amplification factor of a vacuum tube is shown at B, in figure 581. The ratio of the grid and plate voltages used when the grid voltage reduces the plate current to zero is the amplification factor of the tube. The measurement of this is taken for various plate voltages, and the average of the readings used as the correct number.

Fig. 582. Jewell Test Set for Vacuum Tubes.

Characteristic curves of vacuum tubes are useful in weeding out the tubes of low efficiency, and since the increase in the number of counterfeit tubes of various brands, the demand for some apparatus which could be used for this purpose has produced the testing set of the type illustrated in figure 582. This can be used for matching tubes for radio-frequency circuits, for determining the correct grid bias to use, and for finding the mutual conductance, amplification constant and output impedence. The meters in this testing set are also useful in measuring the resistance of telephone receivers, transformers, etc.

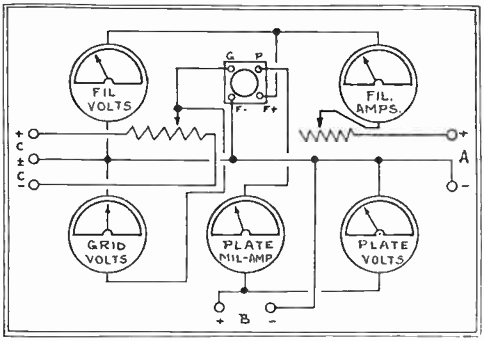


Fig. 583. Diagram of Jewell Radio Test Set.

463. The measurement of current of small quantities, in a receiving set, or other testing apparatus, is sometimes determined by the audibility method alone. A calibrated resistance box comes mounted in a form especially convenient for this purpose, and is known as an *audibility meter*. For comparing the strength of signals from different stations, this meter is shunted across the telephones, as shown in figure 584. It is fitted with a switch and contact studs, the latter being marked in calibrations of the audibility compared to the current required to produce the least audible sound in the telephones connected with the meter. When used in this manner, then, the telephones are included with the meter and used instead of those ordinarily employed with the receiving set. While not very accurate, these audibility measurements are of some value as indicating the comparative strength of the signals from various transmitting stations

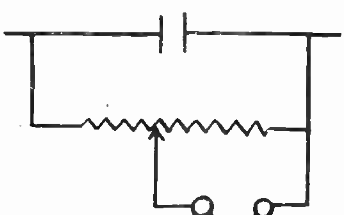


Fig. 584. Audibility Meter.

at any particular receiving station. The readings taken at one station would be of no value at another any distance from it.

464. In the use of measuring instruments the following precautions should be observed, and the following possible sources of error borne in mind.

The degree of accuracy of the instruments, standards and methods should be known. Accuracy and sensitivity are not necessarily the same thing. A measuring instrument might be very sensitive without being accurate. For some purposes approximate measurements are sufficient. For others results must be precisely accurate. Quoting from Farmer, "An indicating instrument may be so sensitive that a change of 0.1 per cent in the quantity being measured can be detected, but, due to defects or errors in the design, it is not reliable to less than 1 per cent. Obviously the latter limits the accuracy of the instrument. Again the certified value on a certificate accompanying a standard resistor may be given to 0.05 per cent, or 5 parts in 10,000, when the limit of reliability is only 0.2 per cent due to thermo emfs, a temperature coefficient or change in potential drop with current because of improper location of the potential taps."

Generally, if accurate results are desired, more than one reading should be taken, with changed conditions if possible. For instance, in a measurement of volt drop, if several readings are taken, with different amounts of current, and the average of these readings taken, the result will be more accurate than would a single measurement.

The scale, or range, of a measuring instrument should be such that there will be a reasonably large deflection. If this shows only a small change for the quantity being measured slight errors are less noticeable than when the range is greater.

The possibility of stray magnetic fields should be kept in mind, and measurements made as far as possible from neighboring conductors, machinery, steel structures, etc. Meters with magnetic shields can be obtained, but the shield can not be relied on to prevent all errors due to such causes. The effect of stray fields may be detected by turning the instrument through an angle of 180°, with the quantity being measured remaining constant, and observing the performance of the indicating device.

In the use of the various types of bridges for measuring purposes, care should be taken to avoid "leakage" or shunt circuits. This can be prevented by use of a "guard" circuit. The purpose of this is to keep all of the points to which current might leak at the same potential as the highest potential in the apparatus, or it may shunt the leakage current around the measuring instrument.

The temperature of the hand, if it is laid on the galvanometer in a bridge, for instance, may be sufficient to cause an inaccurate reading. And if dissimilar metals are used in the construction of a bridge, thermo emfs. may be produced at the joints, which may throw the indicating instrument out of balance and give an incorrect reading of the actual quantity being measured.

Avoid rubbing measuring instruments having glass or hard rubber cases with a dry cloth. If they must be dusted use an oiled cloth. The friction when dry may easily cause an electrostatic charge which will affect the moving part of the meter sufficiently to change its deflection considerably.

When permissible, ground meters used for extremely high potentials, being careful to have the moving coil of the instrument on the ground side. In high-potential work, the electrostatic attraction between the moving and fixed parts of measuring instruments is sometimes very troublesome. If grounding is not possible, the moving part may be thoroughly insulated from the ground and connected to the case or to an electrostatic shield consisting of a cage of wire netting surrounding the instrument.

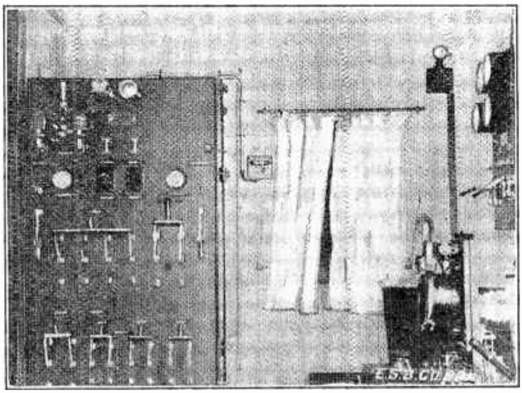
Delicate measuring instruments should always be mounted in such a manner that they will be protected from mechanical vibrations, as slight jars may interfere with their functioning properly.

CHAPTER 39

The Practical Use of Storage Batteries

Duties of Marine Radio Operator Regarding Storage Batteries—Mixing Electrolyte—Specific Gravity—Temperature Effects—Hydrometer Readings—Normal Charging Rate—Capacity Rating—Evaporation—Precautions and Care—Troubles and Repairs—Lamp-Bank Resistance—Carbon Burning—Straightening Plates—Ironclad, Exide, Chloride Cells—Edison Cells—Operation of Marine Charging Panel—Type Numbers—Storage B Batteries—Charging Rectifiers—Calculating Power Bills for Charging.

465. The care of the *auxiliary storage batteries* is one of the most important duties of the practical radio operator



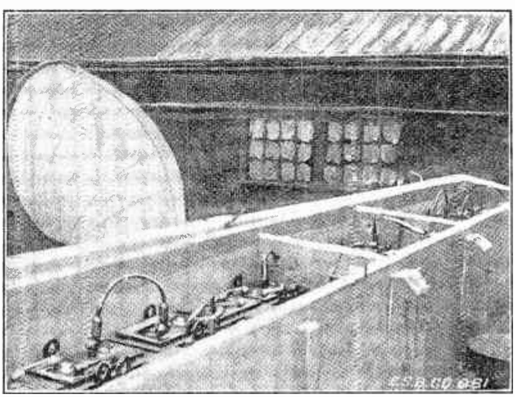


Fig. 585. Battery Installation on Board a Ship.

on board ship. Too much stress can not be placed upon this statement. It is easy to neglect the storage batteries, when all is going well; but if anything goes wrong, and the auxiliary source of power is not in working order, this fact may be driven home by tragic experience. The types of storage cells most likely to be used by the marine radio operator are the *Exide* or the *Edison.* A description of the Exide and Edison cells is given in chapter 25 of this book. The following relating to Exide cells is taken from the literature of the manufacturers of the *Exide cell,* who should be the best authority on the care of their own product.

"The electrolyte consists of a definite mixture of 'pure' sulphuric acid and distilled or other 'pure' water. The sulphuric acid must be 'chemically pure' to a certain standard, which is the same standard as is usually sold in the drug stores as 'CP,' or by the chemical manufacturers as "battery acid." Do not confuse "chemically pure" sulphuric acid with "full strength." In mixing the electrolyte the following precautions should be observed;

1—Use a glass, china, earthenware, rubber or lead vessel; never metallic, other than lead.

2—Carefully pour the acid into the water; *not* the water into the acid.

3—Stir thoroughly with a wooden paddle and allow to cool before taking hydrometer reading of the strength.

Electrolyte, like most substances, *expands with heat,* affecting the hydrometer reading. To compare different hydrometer readings, therefore, the *temperature* should be about the same. It is a known fact that *every 3 degrees increase in temperature decreases the hydrometer reading 1 point,* and this fact can be used in estimating what the hydrometer reading would be at normal temperature. The normal is taken at 70 degrees Fahrenheit. *If the* hydrometer reading at 100 degrees is 1.270, it would be 10 points more, or *1.280 at 70 degrees. When the temperature is much above or below normal, hydrometer readings should be corrected for temperature.* Some hydrometers are combination hydrometer and thermometer, showing in red ink the temperature of the electrolyte, while at the same time giving the specific gravity readings in black ink. By specific gravity is meant the relative weight of any substance compared with water as a basis.

Installation: The battery room or enclosure should be well ventilated, dry and of moderate temperature. *Keep the battery out of the direct sunlight.* Make sure that the positive lug of one cell adjoins the negative lug of the next throughout the battery. *When connecting battery to switchboard and generator, arrange so that positive of generator will connect with positive of battery.* Test charging

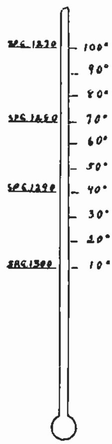


Fig. 586a. Effect of Temperature on Hydrometer Reading.

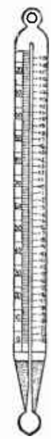


Fig. 586b. Temperature-Correcting Thermometer Hydrometer.

wires from generator for positive and negative with a voltmeter, or as follows. Dip the ends of the wires in a glass of weak salt water and, with the generator running, fine bubbles will be given off from the negative wire. Do not allow the ends of the wires to touch.

The *specific gravity* of all cells in a battery on discharge and charge falls and rises together, so that a reading of the specific gravity of the electrolyte of one cell, termed the '*pilot cell*' will indicate quite accurately the state of discharge or charge of the battery as a whole at the time the reading is taken. For the pilot cell select a cell about the middle of the battery, and keep the level of the electrolyte at a fixed point (one half inch above the plates) by adding a little water at frequent intervals. The proper height can be marked by a paint line on the outside of the jar.

Charging: In regular operation there are two kinds of charges to be given a battery, as follows, "regular charge" given as often as necessary in order to recharge the battery after discharge, and the "equalizing charge" to be given once every week, which is merely a continuation of the regular charge at half normal rate, and is given chiefly for the purpose of keeping the battery in good condition by correcting any irregularities which may develop. The equalizing charge must never be omitted. Charge until all cells gas freely at the normal charging rate, and the specific gravity of the pilot cell rises to within 2 or 3 points of the maximum reading obtained on the last preceding equalizing charge, *then stop the charge.* Before stopping the charge, read the gravity of the pilot cell to check state of charge of battery."

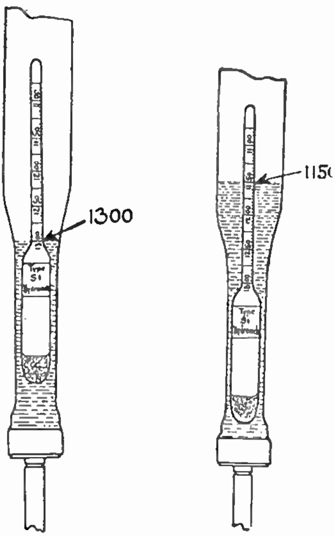


Fig. 587. High and Low Specific Gravity Readings.

466. The *normal rate of charging* of a storage battery is the number of amperes that should be used while charging it. This depends upon the capacity of the cell, and is generally marked on the outside of the cell by the manufacturer. In case this is not marked on the cell, a safe charge can be based on one ampere for each positive plate in the cell, remembering that batteries are generally constructed for an eight ampere hour charge. If, after charging at the rate of one ampere for each positive plate, there is no excessive gassing, the rate may be safely increased to an amount approaching the eight ampere-hour charge. When this is done it is necessary that the operator should keep close watch of the temperature of the electrolyte, by means of a thermometer. The temperature of the latter should never be allowed to rise above 100 degrees Fahrenheit during charge. An Exide cell should give a voltage of 2.1 to 2.5 volts when fully charged, and should not be allowed to fall below 1.8

volts. The battery plugs should be removed while charging to allow the gas to escape.

The capacity of a cell depends upon the size and number of plates. This affects the ampere-hour capacity only and has nothing to do with the voltage of the cell. If a cell is charged or discharged above its capacity, the plates may buckle. Charging and discharging rates are usually about the same.

467. To replace water lost in evaporation use only the purest water obtainable. Just before giving the equalizing charge is the best time for adding water. The fully charged specific gravity of the Exide cell is from 1.250 to 1.300. At complete discharge it is about 1.150. To adjust low gravity, add new electrolyte of 1.250 gravity, instead of water when replacing evaporation until adjustment is made. Then stop adding electrolyte and replace all further evaporation with pure water. If the gravity at the end of the equalizing charge is considerably below 1.250 the quickest way to raise the gravity is to draw all the electrolyte from one cell; refill it with electrolyte of 1.250 specific gravity and add sufficient 1.300 specific gravity electrolyte to that drawn off from the first cell to raise it to 1.250, then draw off the electrolyte from the second cell and refill this with 1.250 electrolyte and so on throughout the battery. Never add electrolyte of higher gravity than 1.250 directly to the cells. To adjust high gravity remove some of the electrolyte and replace with water. *Never add acid to a cell,* as it mixes with water slowly, and will ruin the plates. Read the specific gravity of each cell with the hydrometer syringe at the end of the equalizing charge and record the readings in a note book. If the specific gravity of one of the cells falls below that of the surrounding cells, or there

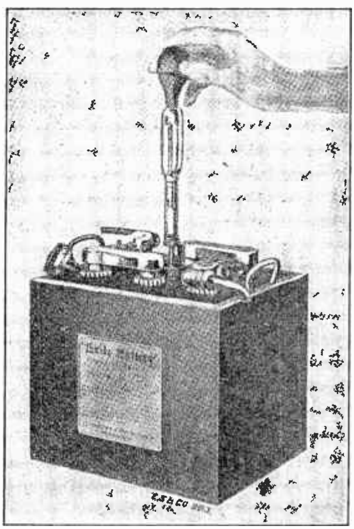


Fig. 538. Taking a Hydrometer Reading.

is a lack of gassing of one cell as compared to the surrounding cells, or the color of the plates is much lighter or darker than those of the surrounding cells, *look for a short-circuit in that cell.*

468. Keep the battery room well ventilated. *Never bring a flame or spark, such as a candle, lantern or lighted cigar or pipe near the battery when charging.* The gas produced by charging is explosive. Keep the battery and surroundings dry and clean; grease or vaseline applied to terminals will prevent corrosion. If electrolyte is spilled or surroundings are damp with acid, apply a solution of cooking soda and water, then rinse with water and dry; do not allow soda solution to get into the cells. "The *sediment* which collects underneath the plates need cause no alarm unless in time it should touch the plates. If the sediment comes to within ¼ inch of the plates, it must be removed. Pour off the electrolyte into a clean receptacle of glass, china, earthenware or lead. Remove sediment, taking care that the two hard rubber plates and the alloy support holder are not thrown away. Then reinstall the element, add enough 1.300 specific gravity acid to the old electrolyte drawn from the cell to bring it up to 1.250 gravity, so that it may be used in the cell. Give a long charge at one-half the normal rate until the gravity and voltage have been at a maximum for ten hours." If the cell is over-discharged, or allowed to stand unused for a long time without recharging or emptying the electrolyte, the plates may become covered with a hard crystalline substance, which is formed by the accumulation of the sulphuric acid upon the plates. This is termed *"sulphating."* A long, slow charging will generally remedy this condition. It is these crystals dropping to the bottom which cause the sediment referred to above.

469. "Batteries not in continual use need 'storage' care. If a battery is to remain out of use for a long time it is best to put it away dry. *Fully charge the cells;* then empty, and fill with pure clean water and allow to stand four or five hours. Unseal the cells and pull out of the jars the elements complete with covers, that is, without removing sealing nuts. Remove the wood separators. Where there are rubber separators replace them between the plates. Allow the

plates to drain and thoroughly dry. Pour the water out of the jars. Put the elements back into the jars but do not seal. Put a tag on each battery, giving the date put into storage. Unless the battery is new, it will be found advisable to throw away the old wood separators, otherwise, they must be stored in a very weak battery solution. When a number of batteries are to be held in wet storage, the most satisfactory results can be obtained by charging continuously at a very low rate, which is so low that gassing is avoided and yet gives enough charge to maintain the batter-

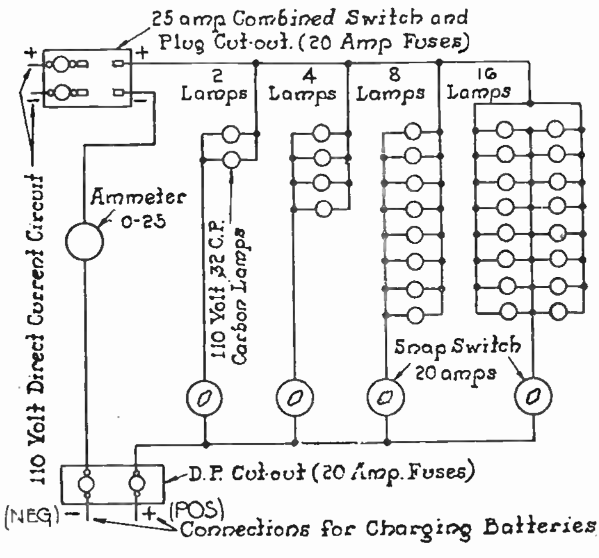


Fig. 589. Lamp-Bank Arrangement with Snap Switches for Quick Changes from One Resistance to Another for Different Banks of Batteries. (E.S.B.)

ies in good condition. It has the advantage of keeping the batteries in condition for putting into use at any time on short notice. Connect a tungsten lamp or lamps of appropriate resistance in series with the cells, across a charging system adapted for continuous charging. Every two months interrupt the trickle charge, remove filling plugs, add water, replace and tighten filling plugs and continue trickle charge."

TABLE OF APPROXIMATE LAMP RESISTANCE FOR VARIOUS NUMBERS AND SIZES OF CELLS

(Lamps rated at 110 volts. Combinations given are to be used in series with batteries across a bus of 105 to 115 volts.)

Approximate Current	0.05 Amp.	0.10 Amp.	0.15 Amp.
Number of cells usually 3 to a battery, 3................	5 15-watt lamps in series	3 25-watt lamps in series	2 25-watt lamps in series
Number of cells usually 3 to a battery, 30...............	2 15-watt lamps in series	1 25-watt lamp.	1 25-watt lamp.
Number of cells usually 3 to a battery, 45...............	1 15-watt lamp.	2 25-watt lamps in parallel.	3 25-watt lamps in parallel.

If the number of batteries to be charged varies from time to time, a lamp bank is a very convenient method for charging. Thirty ordinary lamp sockets are mounted on a board and wired up to snap switches in groups containing two, four, eight or sixteen lamps. A suitable main switch, fuse cutout, ammeter and terminal block complete the connections. If 32-candle-power lamps are not available, then double the number of 16-candle-power lamps. If tungsten or other high-efficiency lamps are used, more will be required than if carbon-filament lamps are used. If the battery is to be charged from a 220-volt circuit, use two lamps in series in place of each of the lamps necessary when charging from 110 volts. Instead of lamps, *resistance units* of approximately 35 Ohms resistance and 3.3 amperes capacity each may be used. This equipment will occupy less space than the lamps and serve the same purpose, each resistance unit replacing two lamps.

470. *Repairing Exide Batteries:* To repair Exide batteries it is necessary to be equipped with suitable charging equipment, hydrometer syringe, a battery thermometer, a lead-burning outfit, and the usual pliers, etc. "Lead joints in a battery are made by melting the parts to be joined and forming a solid weld. The process is called 'lead burning' and is carried out by means of a burning outfit. Where burning must be done on the job away from a repair sta-

tion, the carbon-burning outfit is recommended because it is easy to carry. The carbon-burning outfit consists of a carbon holder with cable, clamp and ¼-inch carbon rods. One terminal of a spare 6-volt battery is connected by a piece

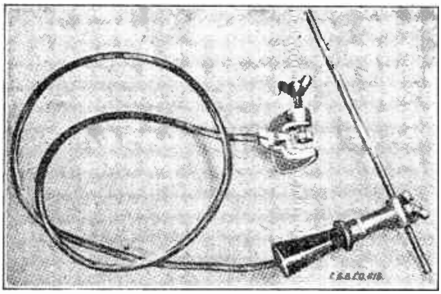


Fig. 590. Carbon Lead Burner.

of cable with the connector to be burned. The cable can be made fast to the latter by means of a clamp and care should be used that the surfaces are clean and a good contact secured. The cable attached to the carbon holder is then connected to the spare battery at the other terminal. The number of cells used should be sufficient to heat the carbon to at least cherry red while it is in contact with the joint. The carbon should be sharpened to a long point like a lead pencil and should project about 1 inch from the holder. The latter should be cooled occasionally by plunging it, carbon and all, into a pail of water. After being used for a short time, it will be found that the carbon will not heat properly, due to a film of scale formed on the surface. This should be cleaned off with a knife or file, as occasion requires. A pair of dark glasses should be used with this outfit.* To remove connectors take a wood bit and bore the connectors ¼ inch deep centrally over each post. *Buckled plates* may be straightened by placing the element in a vice, leaving the pile in the vice for some minutes during the operation to give the plates a chance to straighten without undue strain. The vise jaws should be covered with soft metal or wood strips for protection against injury of plates. A specially designed wrench is provided for removing the sealing nuts, when desired." A stock of spare battery parts should be kept within reach, and these should include some

*In repair stations acetylene, or a mixture of oxygen and illuminating gas, is used for lead burning. A step-down transformer on alternating current is not practical. See Exide Manual, SLI, Electric Storage Battery Company, Philadelphia.

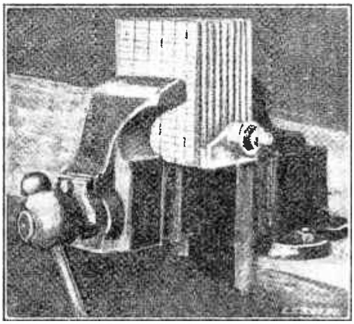


Fig. 591. Straightening Buckled Plates.

emergency electrolyte, to be used in case of spilling, some sealing compound for resealing cells, a strip of lead for lead burning, some vaseline for greasing the terminals to prevent corrosion, and some acid-resisting paint. The paint is a black asphaltum compound, and is a useful insulating paint for all types of electrical apparatus.

471. There are several other types of lead cells, besides the "Exide," conspicuous among which are the "Ironclad" and the "Chloride." The *Ironclad* cells are chemically the same as the Exide and are manufactured by the same company. They are more rugged in construction. The negative plates are the same as in the Exide; but the positive, instead of consisting of the usual "pasted" and dried "grids" is composed of lead rods enclosed in cylindrical hard rubber tubes, which are perforated to allow the electrolyte to reach the rods. The rods are coated with peroxide of lead. (PbO_2.) The *Chloride* cells also have the same negative plate as the Exide, but in this case the positive is made up of soft corrugated lead ribbons, rolled into flat spirals, which are imbeded in a solid support of thick lead.

472. The storage battery auxiliary supplied with the usual ship set consists of 60 cells, in two banks, having a voltage of 120, and a capacity of 224 amperes for four hours.

Figure 478 is a photograph of the standard charging panel manufactured by the Electric Storage Battery Company.

The panel is equipped with a double-throw six-pole switch for changing from charge to discharge. A polarity-reversing switch is included, which has the advantage of making a change from one polarity of the line to the other possible without the inconvenience of changing the connections. This is important in case of a temporary change of polarity in the main line when the dynamo is being rewired, etc. An underload-overload circuit breaker is installed, and arranged so that it will open on an *overload in either direction,* from the main line, or from the batteries. The ampere-hour meter is connected in series with one bank of batteries only. This is done because the charging of each bank in the outfit will be the same; and if the ampere-hour meter were connected in series with both batteries, the reading would be double the charging rate.

In *operating the ESB switchboard,* first determine that the reversing switch is closed in the proper direction by observing whether the voltmeter reads when the plug switch is in the lower left-hand receptacle. If it does not read, reverse the reversing switch. The voltmeter circuit is normally open and a push-button is provided on the switchboard for closing the circuit for taking a reading. This is done to prevent inductive effects from damaging the meter.

For *charging the battery,* close the circuit-breaker, at the same time holding up the plunger of the low-voltage release coil, and then close the 6PDT switch to the left. The red pointer on the ampere-hour meter should be set at ampere hours given in the table. The black hand of the ampere-hour meter indicates the state of discharge of the battery at any time. As soon as charging begins, the black hand starts to move towards zero. When it strikes zero, it will automatically operate the no-voltage circuit-breaker. For a monthly overcharge, it is necessary to remove the cover from the ampere-hour meter and turn the black hand halfway back to the red hand. The ampere-hour meter should be overhauled and recalibrated about once a year.

In case the *ship's dynamo is shut-down,* care should be taken to open the radio-circuit switch and all battery switches.

The *ship's lights* should not be operated from the battery except in emergency.

473. The *type* of an Exide cell can be determined by looking on the battery name plate, which is on the battery case. For example, a name plate may be marked "Type 3-XC-13-1."

The first numeral means the number of cells in the battery. In this example, the battery is therefore a 3-cell battery.

The letters, XC in this example, indicate the type of cell.

The numeral following the letters gives the number of plates in each cell, thirteen in this battery.

The last numeral indicates the arrangement of cells in the battery case, these cells being side by side.

When referring to rating, the number of cells per battery and their arrangement are omitted; the above would be referred to as Type XC-13 cell.

RATINGS AND SETTINGS

(These apply only to the standard arrangement which includes a battery of 60 cells, all of which are discharged in series, but which are charged and floated from a 110-volt bus in two parallel sets, each of 30 cells in series.)

TYPE OF CELL*	Plates Per Cell*	Setting of Overload Circuit Breaker	Setting of Ampere-Hour Meter Red Hand	Resistances for Charging Each Set of 30 Cells	Minimum Size of Wire from Battery to Switchboard	110 Volt Mazda Lamps for Floating Each Set of 30 Cells	Specific Gravity Drop for 4-Hour Discharge
		Amperes	Ampere Hours	In Parallel	B.&S. Gauge	Watts	Points in Gravity
KX	9	40	50	1—No. 5E	No. 10	40 to 50	94
MV MVB MVY Exide	7	40	65	2—No. 7.5E	No. 10	50 to 75	101
	9	60	85	2—No. 6E	No. 8	50 to 75	104
	11	70	100	2—No. 5E	No. 8	75 to 100	106
	13	70	125	3—No. 6E	No. 6	75 to 100	107
	15	80	150	3—No. 6E	No. 6	100 to 150	108
MVS	9	60	85	2—No. 6E	No. 8	40 to 60	58
	11	70	100	2—No. 5E	No. 8	50 to 75	59
	13	70	125	3—No. 6E	No. 6	50 to 75	59
PV PVB	7	40	50	1—No. 5E	No. 10	40 to 60	103
	9	50	70	2—No. 7.5E	No. 10	50 to 75	108
	11	50	90	2—No. 6E	No. 8	50 to 75	111

*To identify type and plates per cell, note the marking on the nameplate, but disregard the first numeral, which refers to the number of cells in the battery. For example, with nameplate marked 60-MV-11, look for MV-11 in the table.

474. Information concerning the *Edison cell,* from literature of the Edison Storage Battery Company, is as follows:

The specific gravity of the solution used in the Edison cell does not change during charge or discharge, therefore hydrometer readings are of no value, except in cases of extremely high or low temperature. Extreme temperature will shorten the life of the battery. The correct length of charge depends upon the extent of the previous charge. If the battery is totally discharged, it should be recharged at the normal rate for the proper number of hours. Both rate and hours are given in the accompanying table.

If the extent of the previous charge is unknown, the cell should be charged until the voltmeter reading has remained constant for thirty minutes at about 1.8 volts per cell, with

ELECTRICAL DATA FOR EDISON CELLS
(*Edison Storage Battery Co.*)

The type of each cell is plainly stamped on cell cover; also (except on the "L", "M" and "W" types) a cell serial number.

Type of Cell	Normal Charge and Discharge Rate in Amperes	Ampere Hour Capacity Normal Rate	Proper Level of Solution	Hours to Charge
A3	22½	112½	½ inch	7
A4	30	150	½ "	7
A4H	30	150	3 "	7
A5	37½	187½	½ "	7
A5H	37½	187½	3 "	7
A6	45	225	½ "	7
A6H	45	225	3 "	7
A8	60	300	½ "	7
A8H	60	300	3 "	7
A10	75	375	½ "	7
A10H	75	375	3 "	7
A12	90	450	½ "	7
A12H	90	450	3 "	7
B1H	3¾	18¾	2¼ "	7
B2	7½	37½	½ "	7
B2H	7½	37½	2¼ "	7
B4	15	75	½ "	7
B4H	15	75	2¼ "	7
B6	22½	112½	½ "	7
B6H	22½	112½	2¼ "	7
G4	30	100	½ "	4¾
G5	37½	125	½ "	4¾
G6	45	150	½ "	4¾
G7	52½	175	½ "	4¾
G9	67½	225	½ "	4¾
G11	82½	275	½ "	4¾
G14	105	350	½ "	4¾
G18	135	450	½ "	4¾
J3	11¼	37½	½ "	4¾
J5	18¾	62½	½ "	4¾
J6	22½	75	½ "	4¾
J7	26¼	87½	½ "	4¾
J9	33¾	112½	½ "	4¾
L20	3¾	12½	½ "	4¾
L30	5⅝	18¾	½ "	4¾
L40	7½	25	½ "	4¾
M8	1	4½	½ "	8
M20	2½	11¼	¾ "	7
W2T	½	2½	½ "	7

normal current flowing. An ampere-hour meter used in charging Edison cells should be set so that the battery is recharged 25 per cent. in excess of discharge. (Set ampere-hour meter to operate 20 per cent. slow on charge.)

"If the battery is seldom completely discharged in regular service it is advisable at times to give it an overcharge. Before starting an overcharge, the battery should be discharged completely and the solution brought to the proper level as given under Electrical Data in the table. (Discharge cells to proper minimum through a barrel of salt water.) Charge for 12 hours the types that under normal conditions are charged 7 hours; and charge for 8 hours those types that are normally charged 4¾ hours. Repeat this overcharge after 30 days service and again after 60 days service.

Always charge at the normal rate except as provided under 'tapering—Current Charge' and 'Boosting.' If the tapering current method is used, with an adjustable rheostat, set the current rate high enough above normal (about 50 per cent) so that as it decreases, due to the rise of the battery voltage, it will average normal, and do not touch the rheostat again until the charge is finished. Charge the same number of hours as though the rate were constant at the normal value. By this method the rate will automatically taper, until at the end of the charge it will be considerably below normal.

Provided the temperature of the solution, in cells near the center of the battery, does not rise above 115 degrees Fahr., the battery may be boosted at high rates during brief periods of idleness, thereby materially adding to the charge. The following table gives figures that may be used under average conditions, but values that will not cause excessive heating must be determined in each case by experience.

5 minutes at five times normal rate
15 minutes at four times normal rate
30 minutes at three times normal rate
60 minutes at two times normal rate

Frothing at the filler opening is an indication that the boosting has been carried too far and the high rate should be discontinued at once.

Edison batteries improve with use. If a battery operates somewhat sluggishly, use it as much as possible, giving it occasional discharges and overcharges, and it will soon pick up. If battery indicates lack of capacity after a long period of service, and an overcharge, followed by three or four normal cycles of charge and discharge does not restore it to normal, the solution should be changed. No solution other than that put up by the manufacturers of the batteries should be used. Do not pour out the old solution until you have received the new and never allow the cells to stand empty. If a battery is to be laid up for any length of time be sure that the plates are covered by electrolyte to the proper height."

475. A summary of the characteristics of the Exide cell and the Edison cell, brings out the following *comparison:*

(1) The lead cell will be injured if charged or discharged beyond its limitations. The Edison cell is not injured by overcharging or overdischarging.

(2) If a lead cell is allowed to stand idle in a charged condition, it will discharge itself in a short time, and its capacity will be more or less permanently reduced, due to the accumulation of lead sulphate. If an Edison cell is allowed to stand idle fully charged, it will hold its charge for a much longer time and will not be injured by this treatment.

(3) If a lead cell stands idle in a discharged condition, it will be injured more than if left in a charged state. If an Edison cell is left idle in a discharged condition, no damage is done.

(4) A lead cell will be badly injured, possibly ruined, by a short-circuit. A short-circuit does not permanently damage an Edison cell.

(5) A lead cell must always be carefully charged at its normal charging rate, or it may be injured. An Edison cell does not necessarily have to be charged at its normal charging rate.

(6) Chemically pure water must be used for making the electrolyte of a lead cell. With the Edison cell, any water which is free from minerals, sulphur, or acids, may be safely used.

(7) The voltage of a fully charged lead cell is 2.1 volts. The fully charged voltage of an Edison cell is 1.2 volt. The fully charged specific gravity of the Exide cell is about 1.250. The specific gravity of the Edison cell is about 1.210

(8) The Exide cell employs an acid electrolyte which eventually destroys its plates. The Edison cell contains no acid, and does not deteriorate from use.

(9) The Edison cell is bulkier, for a given voltage, than the lead cell.

476. Since the widespread use of vacuum-tube receiving apparatus, a knowledge of the use and care of storage batteries has become a matter of greater general interest than formerly. No doubt the filament battery seen most

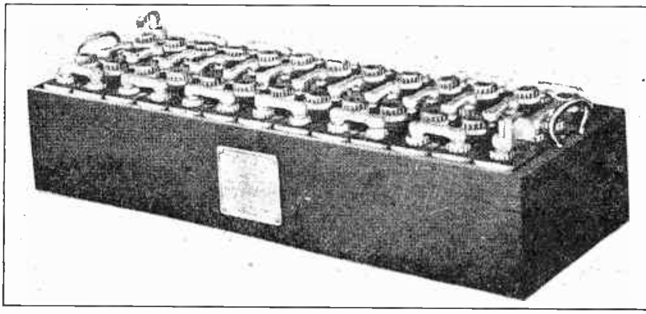


Fig. 592. Exide "B" Battery.

frequently is a six-volt battery of lead cells. The dry-cell B batteries, like the dry-cell A batteries, are most convenient for use in portable receiving sets, or where it is not convenient to charge the storage batteries in the location in which they are used. Where permanent installations are made, however, storage batteries for both filaments and

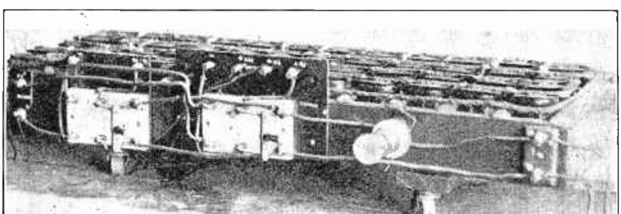


Fig. 593. Photograph of Home-Made Lead-Plate B Battery.

plates of vacuum tubes are a great convenience, saving of expense in the long run, and insure a continually high-voltage power supply for the plates.

It is possible to construct a storage B battery, which, while not having as neat an appearance as the factory-built types, will give quite satisfactory service. A photograph of such a battery, built by the author, is shown in figure 593. This was made in the following manner: Forty-eight tall jelly glasses were fitted rigidly into a wooden framework built for this purpose. Castors were fastened at the corners of the box, to facilitate moving the battery about without lifting. Ninety-six pieces of sheet lead were then cut into paddle-shaped pieces, of which the wider portion was just wide enough to fit into the glass, and the upper narrower portion ½ inch wide and three inches long. Square covers for the glasses were cut from old bakelite panels, and two slits cut near the center of these to accommodate the ½-inch strips of lead forming the upper portion of the plates. The plates were measured to insure that they would be supported ½ inch above the bottom of the glasses when the lead strips were run through the slits in the bakelite and bent over. Several of the plates were then fastened together with a couple of clamps, and holes about one-eighth of an inch in diameter were drilled evenly through the lower wider por-

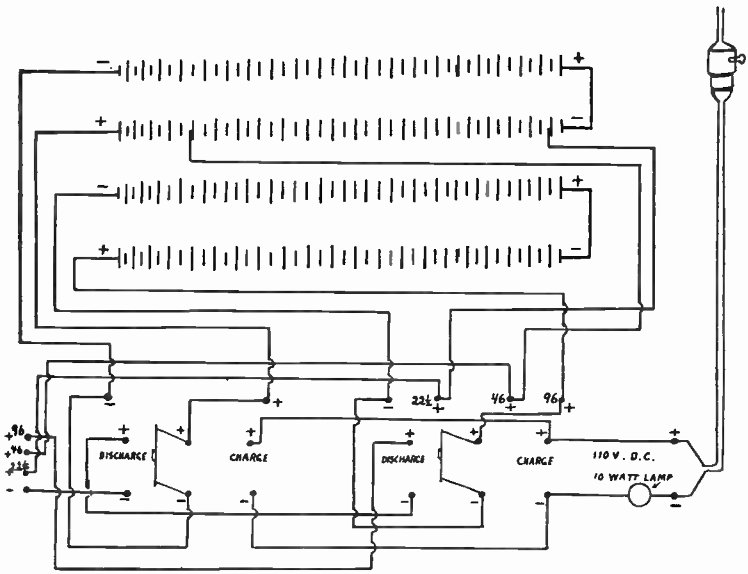


Fig. 594. Diagram of Connections for Battery Shown in Fig. 593

tion, until each plate presented the appearance of a sieve. They were carefully straightened between blocks of wood in a vise, and laid out on a board. The holes were then "pasted" full of a mixture of pure lead dioxide (sold under the name of litharge in drug stores) and glycerine. This was spread smoothly with a putty knife, and the plates allowed to remain undisturbed on the board three days in order to thoroughly dry the paste. They were then placed in the glasses, running the ½-inch strips of lead through the bakelite and bending these over flat to make connectors between the cells and also to support the plates so that they would not touch the bottoms of the glasses. Scraps of bakelite were used for separators. Switches and connections were arranged as shown in the photograph and diagram. Lead wire (solder) was used for making the connections. The glasses were filled to within ½ inch of the top with a 20 per cent solution of sulphuric acid and pure water, and ¼ inch of transformer oil poured on top of this to reduce the creeping salts and evaporation. The cells were connected for charging in parallel with a 10-watt lamp in series with the d.c. charging line.

It is not necessary to move the battery for charging or discharging. When it is desired to use it for operating a receiving set, the switches are thrown to the left, which disconnects the charging line, and throws the batteries in series for discharge. When through using them, the switch can be thrown to the right for recharging, or left open, according to the condition of the cells. It took about three days of continuous charging to "form" the plates in the first place. Gradually the oxide crept across the solution and turned the plates on the positive side of the charging line a dark brown, and left the negative plates pale gray, about the same shade as the pure lead "grids." An overnight charge about twice a week has since kept this battery in splendid working condition, and always "on the spot" with a good 100 volts for the plates of the amplifier tubes of the numerous receiving sets being continually tested in the labora-

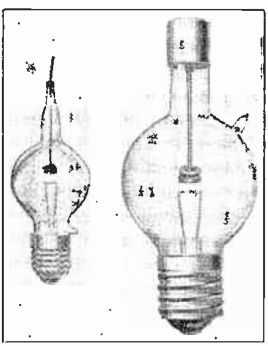


Fig. 595. 2 and 6-Ampere Tungar Rectifier Bulbs.

tory where it is intalled. The financial outlay was small considering the convenience and the greater current capacity than ordinarily obtainable from B storage batteries.

477. It frequently happens that the source of power available for charging storage batteries is alternating current, which cannot be used directly on the batteries as it would not charge them. Many types of rectifiers are manufactured for adapting alternating current for charging storage batteries. They may be given three general classifications: Tube, vibrator and chemical cell. One of the best known tube devices is the Tungar rectifier. It is manufactured by the General Electric Company. These come in various capacities and for half-wave or full-wave rectification. The General Electric Company says: "The name Tungar applies to the hot cathode argon-gas-filled rectifier developed by the Research Laboratory of the General Electric Company. In the Tungar rectifier bulb there is an inert gas, at low pressure, which is ionized by the electrons emitted from the incandescent filament. This ionized gas acts as the principal current carrier, with the result that the bulb operates with a very much lower voltage drop (5 to 10 volts) and is capable of passing a current of several amperes, the current limit depending on the design and size of the bulb. In the 2-ampere, half-wave bulb, the cathode consists of a filament of small tungsten wire coiled

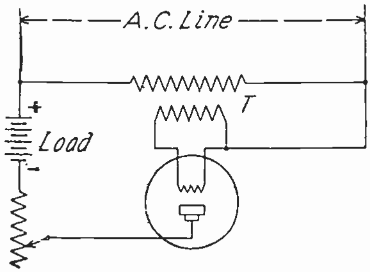


Fig. 596. Half-Wave Tungar Rectifier Circuits.
(T is a transformer.)

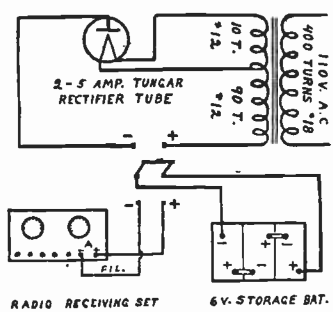


Fig. 597. A Home-Made Half-Wave 2 to 5-Ampere Tungar Rectifier for Charging 6-Volt Battery.

into a closely wound spiral and the anode of a piece of graphite of relatively large cross-section. Certain sub stances are introduced into the bulb at the time of manufacture, which chemically react with any impurities that may be present in the gas within the bulb. This reaction keeps the gas in a pure state throughout the life of the bulb. The purifying agent is seen in the form of a wire ring on the anode. As soon as the tube is started the purifier is volatilized and absorbs any foreign gases, and also somewhat discolors the bulb.

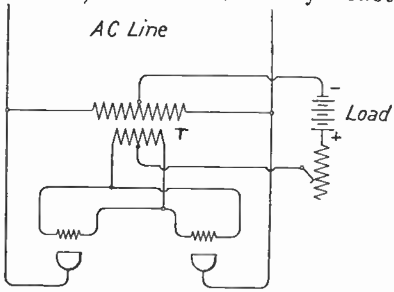


Fig. 598. Connections for Full-Wave Rectification with Two Tungar Bulbs.

The voltage applied to the battery is considerably less than that of the charging line. The following table, showing the performance of a thermionic rectifier rated for three

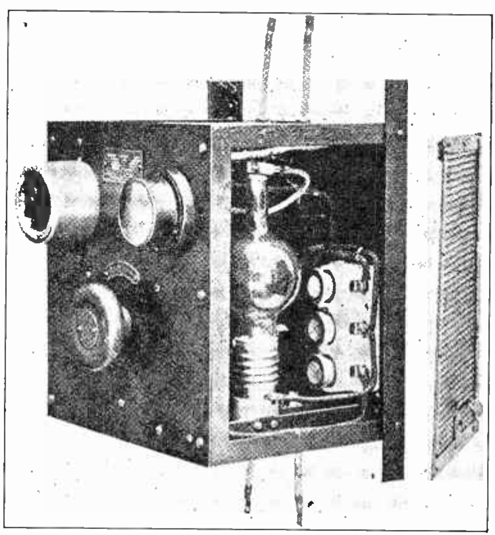


Fig. 599. 75-Volt 6-Ampere Tungar Rectifier.

amperes, will serve to give a general idea of the performance of all rectifiers of this type:

TABLE SHOWING PERFORMANCE OF THERMIONIC RECTIFIER

(*Bureau of Standards*)

Rating.. { Line voltage, 115 volts; frequency, 60 cycles. 7.5 to 15 volts DC, and 5 to 3 amperes DC.

Primary current	Input	Power factor	Battery voltage	Charging current	Output	Efficiency
Amperes	Watts	Per cent	Volts	Amperes	Watts	Per cent
3.50	155	38	2.15	6.00	12.9	8.3
3.05	144	41	4.28	5.15	22.1	15.4
2.70	137	44	6.40	4.45	28.5	20.8
2.40	130	47	8.45	3.80	32.1	24.7
2.03	117	49	10.48	3.05	32.0	27.4
1.78	105	51	12.50	2.60	32.5	30.9
1.40	88	55	14.50	1.92	27.8	31.6
1.15	79	60	16.90	1.42	24.0	30.4
.90	70	68	19.10	1.00	19.1	27.3
.70	63	78	20.90	.80	16.7	26.5
.65	57	76	22.90	.45	10.3	18.0
.55	51	81	24.90	.30	7.5	14.6
.50	40	70	26.90	.02	.54	1.4
.39	40	....	Without battery load			....

(For further theory, curves, etc., of various types of rectifiers, see *Scientific Paper of the Bureau of Standards, No. 265,* 20 cents at Government Printing Office, Washington, D. C.)

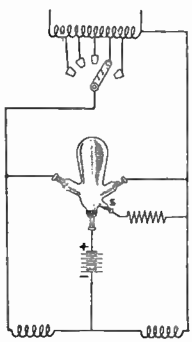


Fig. 600. Mercury-Arc Full-Wave Rectifier.

478. The Cooper-Hewitt mercury valve is employed in various circuits for storage battery charging. Figure 600 illustrates a mercury valve arrangement making use of an autotransformer. It is necessary to tip the bulb to start the arc through the tube between the mercury and the stationary electrodes, first one and then the other of which are in operation. The choke coils shown at the bottom of the diagram serve to keep the arc through the bulb while the current is reversing its direction and the arc is moving from one plate to the other. S is the small starting arc. The mercury arc is also used quite extensively for three-

phase rectification for charging storage batteries. (See paragraph 331 for full-wave three-phase mercury rectifier.)

479. For small currents, such as required for charging one 6-volt bank of cells, a make and break device, operated by electromagnets, is popular for rectifying purposes. These come for either half-wave or full-wave rectification. The full-wave rectification accomplished by these devices is explained in connection with vacuum-tube transmitters, the opposite ends of the secondary of the transformer acting the same for whatever purpose the current is rectified. The full-wave vibrating rectifier illustrated in figure 602 contains two alternating-current magnets, which are fixed in position. The vibrator arm is permanently of north and south polarity, due to its being energized by the battery current. When an alternation passes through the stationary coils in a direction to make both lower ends of these magnets *north*, the *south* end of the vibrator arm will be attracted upwards, and when the lower ends of the stationary magnets become *south*, the opposite end of the vibrating arm will be drawn upwards. This vibrates in synchronism with the reversals of the current, and alternately closes and opens first one side of the lead to the battery and then the other through the contact points C. The clicks can be heard.

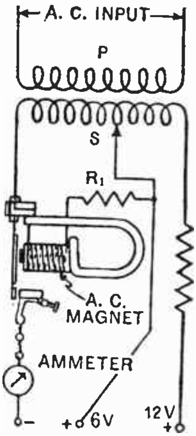


Fig. 601. Half-Wave Vibrating Rectifier.

Chemical rectifiers are described in paragraph 326; and figure 318a, illustrating the connections of four chemical rectifiers for obtaining full-wave rectification, shows the most common method of using these cells for charging storage batteries from an alternating current source. The positive pole of the battery is connected at P and the negative at F. It is possible to use one cell in series with the battery and the secondary of the transformer, if desired.

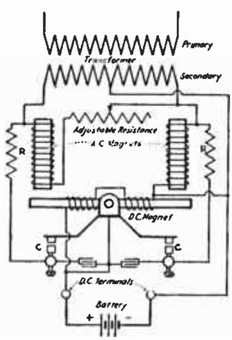


Fig. 602. Full-Wave Vibrating Rectifier.

480. The *efficiency of a storage cell* is the ratio of the power obtainable

from the fully charged cell to the power used in charging it, and is known as its *watt-hour* efficiency. For lead cells this is from 70 to 80 per cent., and for the nickel-iron cell about 60 per cent. This is a lower percentage than is obtained by dividing the ampere-hour output by the ampere-hour input. The ampere-hour efficiency is always higher than the watt-hour on account of current being lost merely by gassing during charging and by local action within the cell. The watt-hour efficiency rating includes the voltage also, and is the usual measure of the total efficiency of a storage battery.

While the voltmeter reading of a cell is some indication of its condition, it is possible to have the voltmeter show the fully rated voltage, on short-circuit with the voltmeter, when the cell is about discharged. Under such circumstances the voltage will drop immediately when a load is applied. For this reason, the voltmeter shunted across the battery terminals when the load is on the battery is more accurate. It will give simply the difference of potential across that one cell.

When cells are charged from city power lines, the *bills* are based on the cost per kilowatt hour. In the District of Columbia this is 7½ cents for lighting systems, with a reduction to 4 cents per kilowatt hour for all power in excess of 120 kilowatt hours per month. If much charging of batteries is to be done, it is to the advantage of the consumer to make arrangements with the power company to have a separate meter on what is called "schedule B." This is the same as that used for motors in machine shops, etc. The rate under this schedule is 7½ cents per kilowatt hour up to 30 kilowatt hours per month, with a minimum bill of $2.00 per month. All power consumed over this per month is at the rate of 4 cents per kilowatt hour. Example: A battery is rated as drawing 6 amperes on charge. At 110 volts, this is 660 watts per hour, or .66 kilowatt hour, and the bill for one hour will be .66 of 7½ cents, or about 4.9 cents.

481. Lead battery clips are practically a necessity in making conections to storage batteries. These are not made of solid lead, but of an iron alloy plated with lead. The ordinary nickel-plated clips with a copper base, used in most

Fig. 603. Lead Battery Clip.

other places where clips are required, are useless around sulphuric acid, as it attacks the copper immediately and within a very few days leaves nothing but a mass of crystals where the clip was. An acid-soaked case will crack and cause a voltage leak. This can be located by testing between the positive battery terminal and the case.

Sometimes a lead cell will be below normal efficiency on account of local action set up between one of the plates and a small particle of foreign material, usually iron, which may be imbeded in it. As it is practically impossible to correct such a fault in the plate, when the impurity has been located, about the only thing that can be done is to remove the imperfect plate and discard it.

When batteries have been charging, do not disconnect the connections to the posts without first opening the charging switch. Also, if lead burning is undertaken, do not do this while the cells are on the charging line. This is frequently done in garages, and has injured several people. The batteries are not dangerous, but careless handling of them is. Some modern makes of lead cells are provided with a safety chamber at the top, for the purpose of allowing the escape of the gases which are the cause of explosions when the cells are handed carelessly.

If acid, or a reserve supply of mixed electrolyte, is kept on hand, it should be put away in a glass-stoppered bottle, with the stopper in tight. Even then, it should be stored as far as possible from fine tools, as the fumes will quickly cover them with rust. And, of course, the bottle should be carefully labeled.

CHAPTER 40

Installation and Care of Radio Apparatus

Installation of Transmitter — Efficiency and Rating of Spark, Arc and Tube Transmitter—Antenna Efficiency—Antenna Current—Splicing Knot—Care of Spark Set on Ship—Care of Arc—Care of Tube Transmitter—Care of Storage Battery—National Electric Code.

482. The success of the seagoing radio operator depends considerably on a knowledge of how to care for the apparatus placed in his charge. He will, under ordinary circumstances, find the apparatus properly installed and tuned to the correct wave lengths. Wiring diagrams and directions are generally placed at his disposal. If, by any chance they are missing, he should be capable of tracing out the circuits for himself.

Directions for using a wavemeter for tuning a transmitter or receiver to a given wave length were given in chapter 38. With a receiver, it is convenient to mark the calibrations of wave length settings on the dials, or these may be kept on a card fastened securely to the wall above the receiving set. The wavemeter is also useful for adjusting a spark transmitter to radiate the wave of low rate of decrement required by law. Resonance curves described in preceding chapters are a help in checking on the tuning of the transmitter.

483. In installing a transmitter, plans should be made for keeping all resistances as low as consistent, to obtain a high efficiency. The condition at which transmission is most efficient is when the greatest radiation takes place at the wave length for which the transmitter is adjusted. The efficiency of a spark transmitter, comparing total power input to power output may not be more than 2 or 3 per cent. Fifteen per cent. is considered high. The power transformer efficiency is usually from 85 to 95 per cent. This shows that the power losses in the spark gap circuit are high in proportion to the power transferred to this circuit.

The efficiency of the antenna circuit may be from 2 to 20 per cent. Under favorable conditions it may be made as high as 50 per cent. It is found by dividing the power radiated by the power transferred to the antenna. The product of these three percentages gives the total efficiency of the apparatus. There may be some confusion as to the ratings of arc and tube transmitters, as they are rated on a different basis. Arc transmitters are rated by the *input*. For instance, a 2-K. W. arc transmitter is designed for operating on 2-K. W. direct-current power input to the arc. Depending upon the characteristics of the antenna, the output will be from 25 to 30 per cent. of the input. Tube transmitters are rated by their *output*. A tube transmitter requiring 2-K. W. power input, will be rated by its output, which will be 500 watts.

Practically every type of transmitting apparatus is equipped with a simple wave-changing switch, and change from one wave length to the other is easily made by throwing this switch. However, when any transmitter is installed, it is necessary to take wavemeter readings of the set, hooked to the antenna, in order to find the proper adjustment of the variable taps to oscillation transformer and inductance coils required for the different wave lengths. After this is done it is only necessary to follow the readings of the antenna hot-wire ammeter to observe resonance, which is indicated by the transfer of energy.

The following table shows the approximate "radiation," that may be expected from spark transmitters on different wave lengths. Allowances must be made for the various types and lengths of aerials:

Type of Set	Wave Length 300 M.	Wave Length 450 M.	Wave Length 600 M.
2 K. W. 500 cycle	3 to 5 amp.	9 to 14 amp.	12 to 17 amp.
½ K. W. 500 cycle	2 to 4½ amp.	5 to 7 amp.	5½ to 8 amp.
1 K. W. 60 cycle	1½ to 3 amp.	....	5 to 7 amp.
½ K. W. 120 cycle	1½ to 3 amp.	....	5 to 7 amp.

The power of a quenched-gap spark set may be increased, up to a certain limit, by increasing the number of discs used in the gap, the power being equal to the square of the number of gaps. However, the note must be clear, maximum antenna ammeter reading not being the only thing borne in mind when adjustments are being made.

The location of the spark gap and condenser may be as shown in figures 154, 476, etc., or as in the early Marconi transmitter, figure 51a, the Oudin coil, figure 112, etc. The latter method is also used in some spark transmitters of the U. S. Navy. While both arrangements are in use, and there is little practical difference in their operation, there are some advantages in connecting the condenser across the power transformer. When the gap is placed in this location, the spark discharge forms a short-circuit across the transformer secondary, which may burn the transformer out. Also it is possible to have a power arc across the gap, interfering with radio transmission. The low-frequency current must traverse the radio-frequency coil in order to charge the condenser on each side, and this may have some effect upon the radiated wave.

484. In the installation of any kind of electrical apparatus, radio or otherwise, the conductor should not carry the mechanical strain of the weight of the apparatus. In a few cases where rigid copper bars are used, these may serve simultaneously as conductors and supports, but wiring should be used only as an electrical part of a part of a circuit and other methods used for holding the apparatus together.

Wires should not be bent sharply to form right angle turns, as this often weakens them at this point. A curved turn can be made to look as neat, and is much better electrically, also preventing power losses by brush discharge at these points. Leads connecting a radio installation to its power supply must be of the correct size of wire and properly insulated. Where it is necessary to splice a wire, this should be done in such a manner that two people pulling at opposite ends of the conductor cannot pull the joint apart. This is accomplished by crossing the wires to be joined, turning them in opposite directions and winding them as shown in figure 604. This is often referred to as

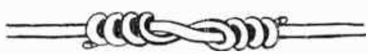


Fig. 604. Splicing Knot.

the General Electric, or Westinghouse, knot. When such a knot is carefully soldered and covered with several layers of friction tape wound neatly back and forth past the edge of the insulation, it will last as long as the rest of the installation. All conduits and cables used for conducting the wires must be grounded.

Switches should always be arranged so that their own weight cannot cause them to drop and accidentally close the circuit in which they are connected. They should swing open downward, so that they must be pushed upward in order to close them.

485. Following are rules for installation of radio apparatus on board vessels of the U. S. Navy, quoted from Robison's Manual of Radio Telegraphy and Telephony:

"The operating room should be well ventilated and lighted, as nearly soundproof as practicable, and free from vibration.

The farther the lead-in is from the conducting bodies the better.

The room should have a well-insulated entrance for the aerial and should be fitted with an operating table about 2½ feet wide, not less than 7 feet long, and of convenient height for working the sending key while sitting down.

The instruments should be mounted on the table so that they are at safe sparking distance from each other and from any part of the operating room.

The receiving instrument should be as far away from the sending instruments as practicable.

The transformer should be where its terminals are not likely to be touched accidentally.

The motor-generator is preferably installed near the operating room, but outside of it. It may be installed in the operating room or in the dynamo room.

The connections between all parts of the sending and receiving instruments should be as direct as possible, and in case of sending instruments they should be of large surface and well insulated. Sharp turns in connecting wires should be avoided on account of brush discharges, which always start at the corners.

High-potential leads should be kept well away from low-potential leads, and where they cross it should be nearly at right angles.

The ground connections should be electrically good and of large area.

The receiver (and transmitter when practicable) should be wired up before installation, requiring only to be secured in place and attached to aerial and ground.

The appliances should be so arranged that the leads con necting the condenser, inductance and spark gap of the transmitter will be of minimum length.

At shore stations means should be provided outside the operating room for disconnecting the aerial from the operating circuit and connecting it direct to ground.

On board ship a lightning switch should be installed which, when in use, will safely and completely disconnect the aerial from all of the receiver and transmitter circuits and connect it direct to ground. (Ground, in this case, is the hull of the ship.)

When necessary to guy the aerial at any point an insulator should be used in the guy line.

The large momentary currents in aerials produce large inductive effects in conductors near and parallel to them. This is more noticeably the case in wire stays or masts, shrouds, braces, etc. They should be grounded.

It should be noted that an aerial wire parallel and near to a long lighting lead or power lead may induce sufficiently high potentials in the lead to puncture the insulation and cause sparking between it and other conductors in the vicinity of combustible material, thereby causing fires. Or it may puncture the insulation and cause a burn-out of an armature, field or transformer. All these effects have been experienced. They are especially dangerous to the wireless sending apparatus.

Protective devices are installed to conduct to ground induced high potential at terminals of primary of transformers, terminals of armature of alternator, terminals of field of alternator, terminals of shunt field of motor (terminals of armature of blower motor)."

486. The daily duties of the operator include the cleaning of his apparatus and a general investigation to see that every part is working in proper order. *An operator should take pride in the bright and clean appearance of his set, as well as in its working condition.* Also, he should realize that those who follow him when he leaves his position will judge him by the condition in which he leaves the apparatus and the operating room. A closet is provided for holding spare parts to be used in case of emergency. The condition of this closet and a record of damaged parts placed in it when new parts were taken out should be included in the station report. A failure to do this may actually be the cause of loss of life, under unusual and extreme conditions.

487. The care of spark apparatus on board ship may be summed up by the following rules:

(1) Keep the oil cups on the motor-generator filled, being careful not to get oil on commutator or collector rings.
(2) Go over the set every day with a screw driver and pliers, to keep all nuts and screws tight.
(3) Keep all switch contacts tight, including the antenna change-over switch.
(4) Tighten the adjusting nut of the quenched gap occasionally.
(5) Wipe the panel and hard rubber rods daily with an oiled cloth to keep them free from dust and moisture.
(6) Put a few drops of oil into the gears of the wave-length and coupling switch.
(7) Test the antenna ammeter daily and, if necessary, vary the inductance of the antenna coil slightly to counteract the effect of sagging of the antenna wires.
(8) Run a piece of clean fine sandpaper under the brushes of the motor and generator every day or two, to clean both the commutator, or collector rings, and the brushes.
(9) Do not exceed the rated power of the transmitter, or adjust the spark gap so as to puncture the condensers.
(10) Don't try to adjust the spark gap or other parts of the high-frequency high-voltage circuits of the transmitter when the set is in operation. If the key should be closed it might cause a fatality.
(11) Don't forget to always reduce all rheostats, etc., to minimum when through using the apparatus, so that it will not be started up again too suddenly.
(12) Keep everything about the receiver clean and bright, binding posts and switches tight and, if possible, protect a crystal detector from dust by use of glass tubing around it.
(13) Give daily attention to the storage-battery auxiliary source of power.

488. In the care of the storage batteries the following general rules apply:

(1) Keep all connections tight.
(2) Keep the tops of the cells clean, wiping them off every day with a solution of ammonia or soda, followed by an oiled cloth.

(3) Always open the vents to allow the gas to escape while charging.
(4) Keep the electrolyte one-half inch above the plates, replacing evaporation with chemically pure water.
(5) Never charge the batteries in a closed compartment or airtight room.
(6) Keep flames, matches and cigarettes away from storage batteries. The gases thrown off while charging are explosive.
(7) Take daily hydrometer readings to determine the state of the electrolyte, also daily voltmeter readings of each cell, with the load on them.
(8) Keep the batteries "lively." Keep them charging or discharging and do not allow to stand idle. Nothing will more quickly deteriorate a lead cell.
(9) Do not overcharge or overdischarge them.
(10) Never lay tools or other conductors down on batteries, which may short-circuit them, discharging them suddenly, and probably buckling the plates.
(11) Keep the batteries out of direct sunlight, as the heat increases the action of the acid on the plates.
(12) Be sure to keep the polarity of the charging connections right.
(13) When a cell appears to have passed its usefulness, melt the top off with a soldering iron and carefully lift the elements out of the container. If the plates are not too badly buckled or sulphated, prepare new electrolyte and clean out the old container thoroughly, returning the plates and new electrolyte and securing the plates into place again by melting the pitch or other substance at the edge of the top.

489. The Arc Manual of the Federal Telegraph Company is authority for the following rules for the installation and care of the *arc transmitter*. (The Federal Telegraph Company prefers to install the apparatus under its own supervision wherever possible.):

In making installations of the 2-K. W. apparatus it will usually be advantageous to arrange the various units approximately as shown in the illustrations, which have been planned for maximum convenience in operation. (See figure 230.) It will be noticed that a space for the receiver has been reserved directly in front of the operator, where he may operate it with his left hand while writing with his right hand. The arc-converter unit is placed at the operator's left so that he may adjust it with his left hand while transmiting with his right. The arc-control panel is placed in the right-hand corner of the operating table, far enough from the wall to permit reaching the various parts on its rear side. A right-hand location for the arc control panel is desirable so that its switches may be reached by the operator with his right hand while he adjusts the arc flame with his left. The antenna loading inductor may be mounted either on the bulkhead, as shown, or suspended from the upper deck. In case it is mounted on the bulkhead, the overhanging end should be supported from the upper deck by the bakelite rod insulators which are furnished for that purpose. The antenna series condenser and send-ground-receive switch are shown mounted upon a small shelf supported by suitable brackets. This location keeps the high-voltage parts where they are not likely to come into contact with the operator's hands and permits the use of direct connections between the condenser and the inductor. The connection from the send-ground-receive switch to the antenna should be as direct and short as possible and located where trouble from the attendant high voltages will be a minimum. The following brief summary of special points to be observed in the installation of certain pieces of equipment may prove helpful:

Arc Converter Unit.

1. Make sure there are no water-leaks inside the chamber.
2. Make a good ground connection, which should be as short as possible, as it must carry the full antenna current.
3. Connect water hose strictly according to diagram.
4. Run hose from pressure regulator out of doors.

Antenna Loading Inductor.

1. Allow ample clearance (10″ to 12″) around inductor on account of high voltage.
2. Allow ample clearance (10″ to 12″) between inductor and iron or steel objects.
3. See that clamp for bare helix on the inductor does not produce a short-circuit between turns.

Chopper.

1. Make all radio-frequency circuits for chopper as short as possible and place the conductors close together to minimize inductance in the chopper circuit.
2. Adjust brush springs to a fairly good tension.

3. Clean commutator with fine sandpaper.

Water Pump.

1. Pump should be located so shaft connecting with cathode rotating gears is in a vertical position, if possible.

2. Wooden or metal strips should be placed beneath pump at each end to prevent springing the base when bolting down.

Water Tank.

1. Should be located above level of arc converter unit to insure water in the chamber, even though the pump is not running.

2. Space should be allowed above tank for filling same.

3. Only fresh water must be used. (Salt water would ground the anode through the hose and short-circuit the equipment.)

Power-Absorbing Resistor (for Model "X" Transmitter).

1. Should be located where air circulation is ample to remove heat.

Electrical Connections.

1. Should be made in strict accordance with diagrams.

2. Following parts should be grounded:
   - (a) Frame of arc converter unit.
   - (b) Frame of arc control panel.
   - (c) Frame of motor-generator.
   - (d) Ground terminal of back-shunt panel (for "K" and "Q" sets).
   - (e) Base of send-ground-receive switch.
   - (f) Base of antenna loading inductor.
   - (g) Base clamps of antenna series condenser.
   - (h) All free metal objects in vicinity of antenna loading inductor or other high-voltage parts.

Don'ts.

Don't overload the transmitter; 8 amperes is the very maximum safe antenna current.

Don't try to run the equipment with a leaky chamber.

Don't try to run the equipment with water in the chamber.

Don't open the chamber or remove the carbon holder until two minutes have been allowed for the carbon to cool. Failure to observe this precaution may result in an explosion.

Don't neglect cleaning the chamber.

Don't touch electrical connections while the apparatus or motor-generator is running.

Don't operate with dirty antenna insulators.

Don't fail to keep mechanical parts clean and well lubricated.

Don't feed the arc too much alcohol, nor take it apart to see what makes it oscillate, nor change the construction of the apparatus.

The Pacific Fleet Radio Bulletin gives the following rules for *care and upkeep of an arc transmitter:* "Keep set neat and clean. *Never* use emery or filings, especially on carbon sleeve water jacket. *Keep* all water connections tight and renew water in tank frequently. *Keep* all insulators clean and in good condition. *Keep* all moving parts oiled but do not use too much oil. *Make frequent inspections and tests of insulation,* tighten all nuts and screws, see all adjustments properly made and are ready for use on short notice. Determine from test or operation the least amount of feed that can be used; how often chamber should be cleaned; how long anode or copper tip can be used before giving it a half turn so as to obtain added life; how fast carbon burns away so as to know when to increase length of holder."

490. The rules given for the care of the motor-generator, power panels, antenna switches, etc., for the spark and arc transmitters, apply in a general way to installations of vacuum-tube transmitters also. High-powered tube stations usually enclose a majority of the wires composing the set and leads to it in lead pipe or cable, which is grounded. This is an all-around protection, and also reduces the undesirable effects caused by feed-backs between these circuits. In a general way, the main precautions to be observed in operating tube transmitters are to avoid overloading, and to be careful about having any loose connections which could drop and form a short-circuit, which would probably blow the tubes. Rules for the care of a vacuum-tube transmitter are given on pages 393 and 466.

When called upon to send an SOS with a vacuum-tube transmitter, or an arc, the operator would of course use the chopper or the tone generator. If an auxiliary spark transmitter is installed, this would be useful in causing a more interfering wave. The Radio Corporation of America has instructed its operators to use a "plain-aerial transmitter," in case of emergency, if tubes are blown, by connecting the safety gap across the secondary of the power transformer in series with the aerial tuning inductances and the ground.

Vacuum-tube transmitters are more critical in adjustment than spark sets. Sometimes corrosion in crevices between the contacts, which would not materially decrease the efficiency of a spark transmitter, may cause a tube set to cease functioning. Such places should be carefully cleaned and polished and put together again, if necessary to look for this kind of trouble. All contacts must be kept very tight. Sometimes the tubes fail to make good contact in the sockets, after the latter have been used for some time. If wires are disconnected, great precaution should be observed that the plate voltage is not allowed to get into the filament circuit. The tubes should not be jarred, especially while hot. Sometimes this causes the heated filament to sag or bend and strike the grid, short-circuiting the tube. Occasionally a glass bulb is cracked by suddenly opening a window and allowing cold air to strike it while it is hot. If water-cooled tubes are used, the temperature of the water should be watched, and where possible it is wise to use duplicate tubes, switching from one to the other in case of overheating from long-continued use. Never undertake to make changes or repairs with the tubes lighted. Always open power switches before touching the transmitter with tools.

491. The National Electric Code, Rule 86, includes the following requirements for the installation of low and medium powered transmitters at land stations:

Antenna and counterpoise conductors must be effectively and permanently grounded at all times when station is not in actual operation by a conductor at least as large as the lead-in, and in no case shall it be smaller than No. 14 B. & S. gauge copper or approved copper-clad steel. This ground wire need not be insulated or mounted on insulating supports. The ground wire shall be run in as straight a line as possible to a permanent ground. Preference shall be given to water piping. Gas piping shall not be used for ground connection. An approved ground clamp shall be used wherever the ground wire is connected to pipes. Other permissible grounds are grounded steel frames of buildings and driven pipes, buried plates, etc.

The radio operating ground conductor shall be of copper strip not less than three-eighths inch wide by one sixty-fourth inch thick, or of copper or approved copper-clad steel, No. 2 B. & S. gauge, and shall be firmly secured in place throughout its length. The radio operating ground conductor shall be protected and supported similar to the lead-in conductors. The operating ground shall be connected to a good, permanent ground, preference being given to water piping. Gas piping shall not be used for ground connections.

When the current supply is obtained directly from the street mains, the circuit shall be installed in approved metal conduit, armored cable or metal raceways. In order to protect the supply system from high-potential surges and kick-backs there must be installed in the supply line as near as possible to each radio transformer, rotary spark gap, motor-generator and other auxiliary apparatus, one of the following:

(1) Two condensers, each having a capacity of ½ mfd. and capable of withstanding 600 volts, connected in series with each other and across the line, the midpoint between the two condensers grounded. Across, in parallel with each of these condensers shall be connected a fixed spark gap capable of not more than one thirty-second inch separation.

(2) Two vacuum-tube protectors in series across the line with the mid-point grounded.

(3) Non-inductively wound resistors connected across the line with mid-point grounded.

(4) Electrolytic lightning arresters such as the aluminum coil type.

In no case shall the ground wire of surge and kick-back devices be run in parallel with the operating ground wire when within a distance of 30 feet. The kick-back protective devices shall not be connected to the operating ground or ground wire.

CHAPTER 41

Troubles and Repair Work

Troubles with Spark Transmitter—Megger in Testing Power Machinery—Action of Motor and Generator With Open—Effect of Generator Voltage Upon Its Frequency—Teting Armature—Emergency Spark-Coil Transmitter—Sparking at Commutator—Freezing of Motor-Generator Shaft—Punctured Condensers—Shorted Quenched Gap—Salt-Water Rheostat—Starter-Resistance Substitutes—Antenna-Ammeter Substitute—Causes for Antenna Ammeter Not Reading—Substitutes for Damaged Antenna Insulators—Soldering and Splicing Antenna—Schackle Insulator—Arc Dont's and Precautions—Troubles with Tube Transmitters—Troubles with Receiving Apparatus—Testing Condenser—Safety Gap on Receiver.

492. It is no particular credit to a radio operator to be able to do his work when everything is going all right, if he is not capable of getting it done somehow when everything goes wrong. Radio apparatus, like other machinery, is liable to get out of order, and troubles are likely to come together rather than singly. But, of course, all of the difficulties mentioned here could not happen at the same time. Certain "stock" troubles may turn up from time to time. Occasionally something out of the ordinary may happen. Experience and natural ingenuity count in locating troubles and making repairs. However, certain methods have been found successful and are passed along to guide the inexperienced.

493. The quickest indication of something wrong with a spark transmitter is *failure of the current to jump across the gap*. If this occurs, the first thing to do is see if the motor generator is running properly. If the motor is running, the d. c. fuses must be all right. If the motor is not running, test for a blown d. c. fuse, by placing a test lamp diagonally across first one fuse and then the other. A blown fuse may be replaced by a spare. If it blows a second time, there must be some condition in the apparatus which is placing an excessive load upon it, probably a short-circuit. If no current comes through the main-line switch, the trouble traces back on the line or to the power supply.

If tested fuses are placed in the a. c. switch-block and, with the motor running, the test lamp will not light when shunted across the a. c. switch, the trouble is likely to be in the windings of the generator, or possibly in the contact of the generator brushes to the collector rings. If the generator output test shows current flowing, possibly the primary or secondary of the power transformer is open. The performance of the safety gap is a convenient means of checking on this. If the safety gap does not spark when the generator is operating properly, the presence of an open in the primary or secondary winding of the transformer may be located by a lamp in seies with the d. c. supply line, as shown in figure 605, at A. This is also applicable to the windings of the motor and generator. The lamp is placed

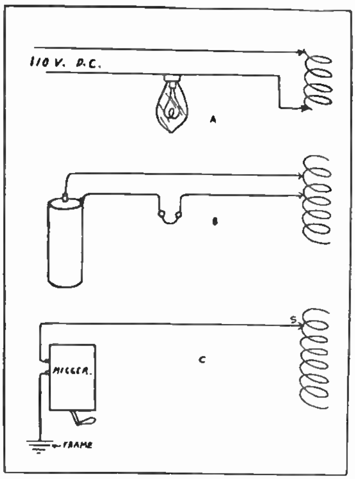


Fig. 605. Methods of Testing Coils for an Open.

across the terminals of the coil, and if a continuous circuit exists, the lamp will light, otherwise not. A telephone in series with a dry cell is sometimes used for this, a click indicating a circuit. However, as the capacity through the coil sometimes deceives the ears, a lamp is more reliable.

The megger, described in chapter 38, is a satisfactory means for locating opens or grounds in the windings of power machinery. One end of the megger circuit is connected to the frame and the other to the coil, as shown at C in figure 605. For testing a d. c. armature with the megger, the contact S is moved around the commutator, from segment to segment, first removing the brushes from the commutator. The field winding of motor or generator may be tested by disconnecting them and making contact with the ends of each section of the winding separately. In these tests, if the coil is grounded to the frame at any point, current will pass through the frame and ground wire of the meter, and the megger pointer will fall to zero. A lamp may be used in the same way, in series with the power line.

Some operators prefer to ring out the windings with a small alternating-current magneto and bell, such as commonly used by practical electric linemen in house wiring, etc. If the bell rings, the alternating current has passed through the winding and there is no open.

The performance of the motor and generator are usually an indication of the condition of the windings and would attract immediate attention. For instance, if a shunt field winding of a compound-wound motor is burned out, the motor will speed up in an erratic manner, due to its operating on only the series field. If the series field in this machine should develop an open, the motor would stop. In a generator, an open in either field will either stop or decrease the output of power, but the motor running it will speed up due to the removal of the load, or pull, of the field magnetism of the generator.

While theoretically the voltage of the generator has nothing to do with its speed, in practice, seeing that a motor of absolutely constant speed is unavailable, every change in the field strength of the generator field of a motor-generator will have some effect upon the motor speed, reacting upon the generator frequency.

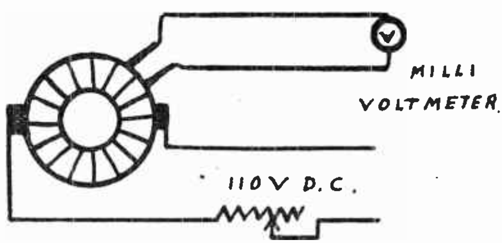


Fig. 606. Bar Method of Testing Armature.

A motor armature may be tested as shown in figure 606. The d. c. power is applied to the armature through the brushes, with the field windings disconnected, and a voltmeter, or lamp, is shorted across adjacent segments of the commutator. A millivoltmeter is sometimes necessary if the armature coils have a high resistance. The voltmeter will give a reading across adjacent commutator segments where the armature coil is intact, showing the drop across this section of the winding. If one of the coils is open no reading will be obtained. This coil may then be bridged with a piece of wire, and preparations made for "lame" operation of the motor until permanent repairs can be made. After the bridge is in place the voltmeter reading across the two segments on the opposite side will be greater than previously.

494. It is possible to rewind a field coil, but repairing the armature is rather a complicated process. Armature winding is a trade in itself. A damaged armature coil can be bridged and the apparatus operated on reduced power until permanent repairs can be made. Ships generally carry spare parts, including an extra armature and shaft for the motor-generator. If spares are not available and it is a case of emergency where the operator is actually obliged to make the apparatus on hand work, he may, by careful and painstaking work be able to rewind the armature. If this is necessary, the damaged sections may be carefully removed, leaving the others intact, and by watching, as the windings are removed, to see how they were put on, the manner of winding may be imitated.

Some vessels carry a spark-coil emergency transmitter, to be used in case of irreparable injury to the power apparatus. This is operated on storage batteries, as shown in figure 607B is an overload circuit-breaker in the battery-charging line.

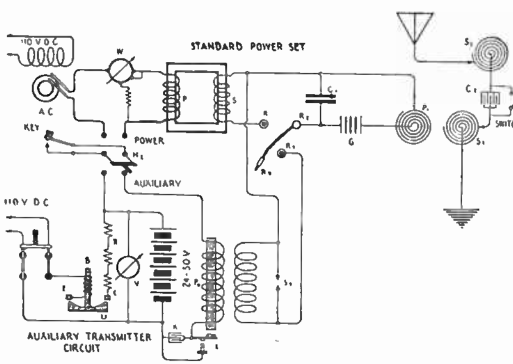


Fig. 607. Emergency Transmitting Apparatus.
(Bucher's Practical Wireless Telegraphy.)

495. If there is *sparking at the commutator brushes,* this is a certain indication of trouble. A heavy ground in the motor, or in the main line, will cause the commutator to throw a shower of sparks when reaching a certain speed, and this will diminish as the speed is decreased. The commutator may be dirty, this causing the sparks. In this case it is easily cleaned by holding a piece of fine cloth against it while the motor is running. Fine sandpaper may be used to smooth down the ridges, if the segments are worn and making uneven contact to the brushes. Never use emery cloth on the commutator, because the small particles of emery are conductors of electricity and, getting into the apparatus, would cause trouble. Sparking may also be caused by the mica segments of the commutator being loosened and protruding. In this case it is necessary to remove the armature and turn it down in a lathe one thirty-second of an inch. The commutator brushes may be out of "neutral field," or more accurately, out of the commutating plane, the remedy being readjustment of the rocker arm controlling the position of the brushes.

496. Overloading the motor-generator, or running it without proper lubrication, will cause it to become overheated, causing unnecessary power losses, and in some cases damaging the apparatus. When a shaft binds so that it will not turn, generally referred to as "freezing," it may be possible to remove it by tapping at one end with a wooden sledge hammer. If this does not start it, remove the under bearing housing and take the rotor out and try hot oil. If it is possible to place the shaft and bearing in a lathe, the bearing can be forced off of the shaft. As a precaution the shaft may then be smoothed off one thirty-second of an inch, while in the lathe. This loss in diameter is then made up for by adding a wrapping of fine bronze or copper shim around the shaft when it is inserted again. A good quantity of powdered graphite and oil should be used when starting the machine up again. If the motor-generator shows signs of being overheated, freezing of the shaft may be prevented by *keeping it going* and oiling it while going.

When loosening any wires forming a part of the transmitter circuit, for the purpose of making repairs, pin a piece of paper securely around each wire, marking plainly its polarity and connection to the apparatus. This may save much time and confusion in putting the set together again.

497. In the case of the spark gap failing to operate when the power circuits of the transmitter are in good working condition, the condenser may be at fault. This is easily recognizable by anyone having a little experience in operating a spark transmitter, by the characteristic sound produced. The spark does not jump the gap, but there is a dull hollow sound when the key is pressed. A punctured condenser should be replaced by a spare if possible. If Leyden jars are in use, it is possible to scrape the copper coating back from the hole with a sharp knife, a distance of about two inches. If this is done on the outside of the jar only, the distance will be too great for the current to jump through from one plate to the other and the condenser will operate temporarily. However, as Leyden jars are seldom found on ship sets nowadays, this is not likely to be done. It is possible to repair a mica condenser, by removing the sections and renewing the damaged plates and replacing them in the container again. This is a difficult thing to do, on account of the original condenser plates having been pressed into the case by machinery, and it is usually hard to get as many sections into the case again as were taken out of it. The paraffine must be melted and poured out before removing the sections of this type of condenser, being very careful not to allow it to catch on fire.

It is often possible to renew the usefulness of a punctured Dubilier condenser by warming it in the oven, the melted paraffin filling the hole in the copper and forming new insulation.

If only one condenser in a bank is damaged, and there is no spare for replacing it, the remaining jars may be connected in parallel, the turns on the loading coil reduced in number to correspond, and the transmitter operated on reduced power. If all of the condensers are burned out, the spark gap may be connected directly across the secondary of the power transformer, in series with the antenna inductance, antenna, and ground, and the set operated as a "plain-aerial transmitter."

It is usually possible to secure some pieces of glass and sheet copper or brass for the construction of an oil-plate condenser, which may be made to serve the purpose of replacing damaged mica condensers until new permanent replacements are obtained.

The cause of punctured condensers is generally a strain put upon them by either too heavy a load or the spark gap being adjusted so as to force them past their capacity. If the condensers are all right, and a quenched spark gap is in use, but does not operate, the plates may touch or be short-circuited by having become carbonized. This can be determined by testing two plates together at a time with a copper fork provided for the purpose, or with a bent piece of wire. If the fork does not show a spark, the current is not passing through it and the gap is short-circuited at this point. This is somewhat dangerous to do, and one should be very careful not to touch any other part of the apparatus while holding the fork, or to have the body grounded through any conductor to the earth or hull of the ship. It is a good idea to wear a pair of rubber gloves when making tests of the high-frequency part of a transmitter in operation.

To remedy carbonized quenched-spark-gap plates, take the gap apart and clean with fine emery cloth, being careful to clamp it tightly in place when it is returned. The insulating bushings should also be inspected, and replaced if necessary.

When a rotary gap is used, the electrodes being improperly adjusted may prevent the spark from jumping the gap.

498. It may be that upon closing the switches, the motor-generator will not start, due to trouble in the starting

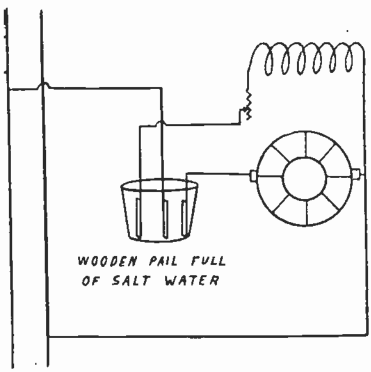


Fig. 608. Salt-Water Rheostat.

apparatus. In some cases, where separate steps of resistance are used, only one of these will burn out, and this may be bridged with a piece of wire, and the set operated as usual. If more than one resistance coil is open, however, this is not wise, and some makeshift must be resorted to. Some operators are able to obtain an extra resistance, such as a carbon from the ship's searchlight, but the usual procedure under such circumstances is to rig up a salt-water rheostat, as shown in figure 608. The illustration is self explanatory. Three metal electrodes are immersed in salt water, and the one connected to the line gradually moved away from the field terminal and towards the armature, thus starting the apparatus up in about the usual manner. Pure water is an insulator, but a few grains of salt give it considerable conductivity.

A bank of lamps may be used as a starting resistance. The lamp sockets are fastened to a board, connected in parallel, and the lamps inserted into the circuit one at a time, allowing the full force of the current to gradually reach the motor as it increases in speed.

If a hand starting box is in use, and the small release magnet which holds the handle in position burns out, this will make an open in the field circuit. This coil can be easily rewound. If it is necessary to use the apparatus immediately, the field connection can be made to the same post as the armature, and the handle moved slowly over the resistance taps by hand, and fastened in place with a block of wood or a piece of string. This is of course only a makeshift to be resorted to in case of emergency.

Lamps may be substituted for field rheostats, or other resistances about the apparatus, in case of damaged parts and lack of spares.

Starting the motor up too slowly is likely to burn out the starter resistance and starting it up too suddenly may damage the armature.

499. If the transmitter is found to be in good working condition, but the antenna ammeter indicates no current, the ammeter is probably burned out. The best thing to do in this case is to connect a lamp in series with the antenna, in place of the ammeter, shunting it with a piece of wire

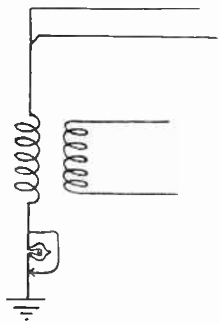


Fig. 609. Lamp Substitute for Antenna Ammeter.

which may be attached in shunt to the lamp after radiation is determined, in order to reduce the antenna resistance. A wire may be bridged across the connections for the ammeter, and sparking at the change-over switch, when the switch is moved, with the set in operation and the key down, will indicate current induced into the antenna system.

If the antenna ammeter is not damaged, but there is no radiation with the set in operation, there is a leakage in the antenna system. This may be due to poor insulators, or to the wires of the antenna hitting some conductor to ground. Leaky antenna insulation can be tested for by placing a spark gap in series. This may be the secondary of an induction coil, or the spark gap of the main transmitter. If this does not spark when the key is pressed, leakage is proved, and the aerial must be taken down, and the insulators inspected. If an insulator is broken or charred, it should be replaced with a spare. Or, if no spares are on hand, a piece of marlin (tarred rope) soaked in oil may be used. Some operators have found glass bottle necks a convenient substitute. These may be connected as at B, figure 610, or as at A. In the latter case a large washer from the pump is inserted into the end of the broken bottle and a solid knot prevents the antenna wire from pulling through this.

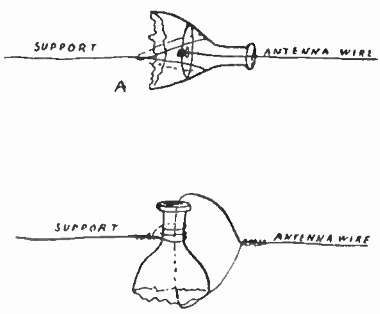


Fig. 610. Bottle-Neck Antenna Insulators.

If the antenna can be easily lowered it is a good idea to clean off the insulators occasionally, as it is the salt spray collecting and charring from the high voltage at the ends of the antenna, which break down the insulation and form a leak across them. Insulators near a smoke stack are usually subjected to excessive heat, which may cause them to crack. Inspect them frequently when in such places.

500. All antenna joints should be soldered to prevent losses due to high resistance. Corroded or loose joints cause reduced power in the radiated wave, and reduce the strength of the signals when receiving.

Figure 611 illustrates a method used for splicing stranded antenna wire, which is difficult to make mechanically strong. The bridge and thimbles can be made of solid wire, or of rope.

Antennæ on board ships are usually guyed and supported more securely than is necessary on land, on account of the roll of the ship and the greater strain put upon the wires. What is called a *shackle* insulator, is generally used between the antenna and the mast.

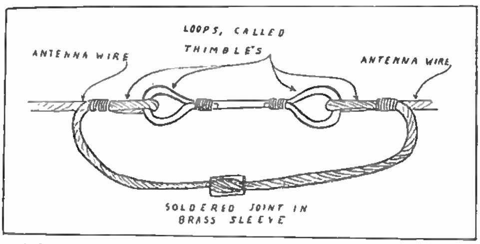


Fig. 611. Splice for Stranded Antenna Wire.

501. If an antenna should be blown down at sea, a new one may be constructed, provided materials are on board. If not, such an aerial as can be made from what is left of the old one, might suffice to handle a distress call, or carry on some other important communication. If the masts were broken down, the highest accessable points on the ship would be used for supporting the wires, as a makeshift.

In case of some unusual damage to the transmitter, such as in times of war, an operator may be called upon to construct an emergency transmitter out of parts of the original set. The antenna inductance can be used as the foundation for a conductively coupled apparatus, and the spark gap connected in the antenna system, or otherwise, depending on materials on hand.

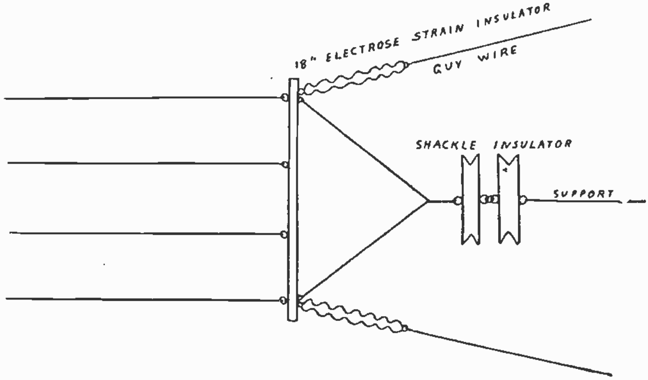


Fig. 612. Ship-Style Antenna Insulators.

502. A seafaring radio operator is frequently called upon to care for an arc. *The Pacific Fleet Radio Bulletin* is quoted on troubles with arc transmitters: "In general, all *troubles with arc transmitters* can be grouped under the following subdivisions: Motor-generator and starter troubles, arc-generator troubles, and insulation troubles. On circuits between motor-generator and arc, there may be grounds or shorts: protective condensers or protective gaps shorted, field rheostats open, starting resistors burned out or of insufficient resistance, loose or high-resistance connections: contactors, overload or series relays on starter improperly adjusted: switchboard meters registering in wrong direction.

Assuming that the motor-generator is running O. K. and switchboard voltmeter proper voltage for striking the arc, the following troubles may occur: If no reading on d. c. ammeter, or no hiss develops when striking the arc, would indicate open-circuit beyond the voltmeter connections and no current passing through the electrodes. If ammeter shows reading on striking the arc but drops again, the fault may be due to the following: Break in antenna circuit; gap too wide; anode tip burned through on account of reversal of polarity, flooded with alcohol, kerosene or water.

If circuit-breaker trips on striking arc, the trouble may be due to starting resistance cut out, or insufficient, allowing excessive current to pass; voltage too high; arc flame touching chamber or pole pieces; heavy ground on antenna circuit.

If arc stops or kicks out while in operation, the trouble may be due to gap distance too great, ground on antenna lead or insulators broken down; ground on anode or positive leg of feeder; dirty or salty circulating water becoming partial conductor and grounding anode; defective carbon; arc flame jumping to pole tips or chamber, may be caused by pole tips being too close or anode body not in proper alignment, cathode or carbon not revolving, causing carbon to burn unevenly and eventually causing short-circuit; ruptured anode, due to no water circulation, or low water pressure, account of obstruction in hose or cross connections of hose to anode, or reversed polarity at anode; heavy gas leaks from chamber, open-circuit develops while operating.

No radiation or very poor radiation may be due to weak magnetic field from wrong connections in arc field coils, shorts in coils, or proper number of sections of coils not cut in for wave lengths used; arc flame not blowing towards chamber door; gap too close, causing spluttering arc; weak insulation; none or not enough hydrocarbon feed; poor hydrocarbon feed, such as water in alcohol or kerosene; unsteady arc, from air leaks, water leaks, low voltage, too wide gap, teats on carbon, cracks in carbon, open in antenna circuit.

If reduced radiation, causes may be gas leaks at carbon sleeve, around pole cores where they enter chamber, through poppet valve, at door, flanges, anode blocks and feed pipe fittings; water leaks in chamber; carbon deposit on anode block and gasket; gap distance too close or wide; poor or no feed; weak insulation; weak magnetic field; loose connections in antenna circuit; reduced power.

Permanent reduction of radiation may be due to power supply limited; small antenna capacity; insufficient antenna insulation to stand high power; too much high-frequency resistance, such as when a copper tubing loading coil is used instead of Litzendraht; improper strength of magnetic field.

Insulation troubles. These are due mainly to the present type of electrose insulators used for antenna suspension. Where exposed to heat they soften, while outside they develop cracks, soot up and are hard to clean. (The Radio Division of the Bureau of Steam Engineering is developing porcelain insulators for above purposes which, when furnished, should remedy most insulation troubles.)

DON'T touch 500-volt circuit or oscillatory circuit while operating.

DON'T allow men aloft while operating.

ALWAYS shut down motor-generator and open supply switches if working around set. (Pull out fuses and leave out until finished, so other people will not be able to start the machine while you are working on same.)

NEVER refill feed cup while in operation, as sparks may pass to can and cause explosion and fire.

ALWAYS stand as far away as possible when opening chamber door after a run.

NEVER put a naked flame near open chamber door after operation.

ALWAYS remove tools after working around arc.

ALWAYS see that carbon-rotating motor is working.

ALWAYS see that water is circulating before striking arc.

ALWAYS see that all receivers and detectors on ship are protected before working arc.

If arc chamber is kept gas tight, better radiation will be obtained and less feed can be used after the arc has warmed up, thus avoiding sooting up of chamber and anode blocks and frequent cleanings.

If generator voltage drops excessively after striking arc, it usually indicates that the series field of generator is bucking the shunt field. Before striking the arc the shunt field is only active and the voltmeter will indicate normal, but as soon as current passes through series field it neutralizes part of the field magnets, if series field is bucking instead of assisting the shunt field."

If the polarity of the copper electrode of the arc is reversed, it will melt almost instantly, allowing water to flow into the arc chamber.

Ice on the antenna, when operating the arc transmitter, is also a cause of transmitting troubles. It may cause the arc to stop or kick back.

Never wear a gold watch around an arc while operating. The steel works are likely to become magnetized, and the case may be damaged.

503. The principal troubles with vacuum-tube transmitters come from improper control of the power supplies to plates and filaments, either overloading the tubes and damaging them, or using insufficient power to obtain results. Fuses should be placed in leads to vacuum tubes in transmitters, thus protecting them from overloads. Troubles with tube sets and operation of same were taken up in chapters 34 and 35.

The location of the antenna ammeter in the vacuum-tube transmitter is important. It has been found that it is better to have it between the antenna and antenna inductances than on the ground side of the system. This is on account of the possibility of the antenna forming a short-circuit to the ground for direct current, in case of accident. One might be looking at the ammeter and observing a reading which was caused by a d.c. short-circuit, supposing this to be the usual high-frequency antenna current. In one case this is known to have happened in the following manner: An operator, in some manner, had allowed a wire leading from the positive side of the filament supply to come in contact with the antenna system. When the transmitter was started up, the ammeter indicated antenna current, and then the tubes blew. He had spare tubes, and immediately upon placing them in the sockets the accident was repeated. It can be seen that with the negative side of the filaments grounded, there was a short through the antenna ammeter to the positive side of the filament circuit. While the short-circuit might have existed had the ammeter been located higher in the antenna system, the meter would not have given the misleading reading, and the existence of something wrong would probably have been noticed immediately.

504. *Receiving apparatus,* having less power to handle, is not subject to as serious mishaps or breakdowns as transmitters. However, they may easily get out of order, and at times require rather delicate work in repairing.

The fact that no signals are heard in the telephones of a receiver is not necessarily an indication that the set is out of order. It is possible that there are no signals to be received. However, if after proving a proper adjustment of a crystal detector, or proper arrangement of batteries in a vacuum tube set, there is a prolonged silence, the receiving apparatus should be overhauled.

With a crystal-detector apparatus, the buzzer tester is useful as an indication of trouble. If no sounds are heard in the telephones, the trouble may be in the battery circuit of the buzzer. Or it may be that there is an open in the telephone cords, or in the wiring of the receiver, or loose connections somewhere about the set. Sometimes the crystal itself has lost its sensitivity or has become dirty. Spare crystals should always be carried for the purpose of replacing those which have deteriorated.

In testing the receiving set for trouble a small flash-light

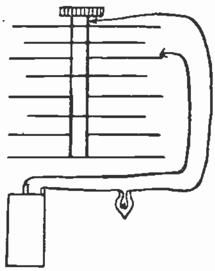


Fig. 613. Test for Variable Condenser.

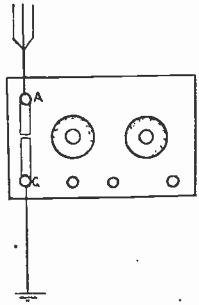


Fig. 614. Safety Gap for Receiver Protection.

lamp in a small socket, with a couple of dry cells is useful. If the lamp lights through any of the wires or coils, this proves that the circuit is continuous. If the lamp lights through a variable condenser, from stationary to rotating plates, the plates touch and the condenser is useless unless the plates can be straightened. In undertaking to straighten the plates, do not use a knife or screw driver, as these will bend the edges of the plates, and it will be very difficult to get them even again. Run a folded handkerchief between the movable plates and carefully pull the entire plate. It is easy to begin at one end and do this through the total number of plates, only to find that the last one does not come out even as to space, so this should be planned for. Sometimes condensers are made so that the movable plates, with the shaft, can be moved a little one way or the other by loosening or tightening a nut.

505. Spare telephone cords may be needed. If the cord is worn beyond repair, it can be replaced temporarily with ordinary bell wire or some flexible lamp cord. Telephones are rather delicate devices, depending upon the permanent magnetism in the iron horseshoes enclosed within the case for their sensitiveness. They should not be dropped or thrown down on the table, or laid on a radiator or other heated place. Either the jar or the heat may ruin the magnets. Telephones which are considered useless are easily repaired, if the magnets are still good. The small spools of wire are simple in construction and can be taken apart and rewound, or spools from an old telephone in which the magnetism has been destroyed may be used to replace damaged spools in otherwise good telephones. Often only the end of the wire leading from one of the spools is broken

and a drop of solder is all that is needed. The polarity of the telephones, especially when used with vacuum-tube receivers, which place the plate battery voltage on the telephone windings, affects their length of life considerably. Some telephones come marked for positive and negative, and there are phone plugs on the market which fit into socket attachments like those used for soldering irons and heating devices, with one contact of different shape than the other, so that it is impossible to insert them into the circuit in the wrong way.

506. Sometimes signals are heard, but are exasperatingly weak. This may be due to the set not being tuned to resonance, or to loose contacts, or to antenna leakage. Sometimes, when an insulated antenna lead-in is used, the wire will break inside of the insulation, giving no external indication of the trouble. This may cause the signals to stop entirely, or, as the ship rolls, striking the ends of the wire and then separating them, the signals may come and go. The lead-in can be tested with a lamp, by attaching one end of the test wire to the lead-in, near the change-over switch, and leaving the other wire quite long, so that it may be moved over the lead-in at both sides of its entrance to the insulator.

Fluctuating signals are often caused by the antenna wires touching a smokestack or guy wire as the antenna swings in the wind, or with the roll of the vessel.

507. To protect the windings of a receiving set from damage from lightning and also from high power when near a high powered transmitting station, a safety gap should be placed across the antenna and ground connections, as shown in figure 614. This consists of two strips of copper or brass forming a gap of about one thirty-second of an inch. The weak energy of the received signals will not jump this gap, but higher power will seek the earth across this space, thus saving the receiving apparatus. The connections to the type-I antenna change-over switch and some other similar arrangements of switches, also protect the receiver by forming a short-circuit across the detector and telephones. This is more of a protection from the transmitter in the same station than from outside power.

Troubles with vacuum tube receiving apparatus are treated in paragraphs 388 to 396.

CHAPTER 42

The Radio Compass

Early History of Radio Compass—Goniometer—Kolster Radio Compass—Bidirectional and Unidirectional Compass Work—Cardiac Curve of Unidirectional Compass—Directions to Operators for Finding Bearing by Radio Compass—Radio Beacon—Installations on Los Angeles and Tender Tulip—German Radio-Compass Loop Control—Table of Wave Lengths of Coil Antennae—Coast Guard Radio-Compass Apparatus—Mariner's Compass Card—Sonic Depth Finder—Supersonic Depth Finder and Communication Device.

508. The *radio compass* had its beginning with the Hertz loop, which, when equipped with a spark gap and moved so as to cut the lines of force of transmitted waves at different angles, indicated the direction of the transmitted electric waves. It did this by producing the most brilliant spark across the gap in the loop when the loop was placed so that its plane was parallel with the direction of the waves, and by producing no spark at all when placed exactly at right angles to these waves. (See figure 129, paragraph 188.) The first attempt to make a practical application of this principle was probably the Bellini-Tossi apparatus. This consisted of two loop aerials, each having a coil formed in a part of their circuit, and the two coils placed at right angles to each other. A third coil was placed in inductive relation to the coils of the twin antenna. The direction of the oncoming electric waves could be determined by moving the third coil until it received the greatest amount of induced energy from either one or the other of the antenna coils. This was determined by observing the amount of current jumping across the grounded spark gap.

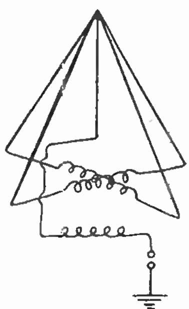


Fig. 615. Bellini-Tossi Direction Finder.

509. Marconi later brought out another type of direction finder which was an adaptation of the Bellini-Tossi apparatus. The Marconi radio compass made use of a crystal-detector receiving set with a buzzer tester, and the two crossed triangular antennæ. The moving coil took the form of a goniometer, consisting of two coils, inside of which was

a third coil known as an exploring coil, which could be rotated. The result of rotating this third coil in the gonio-

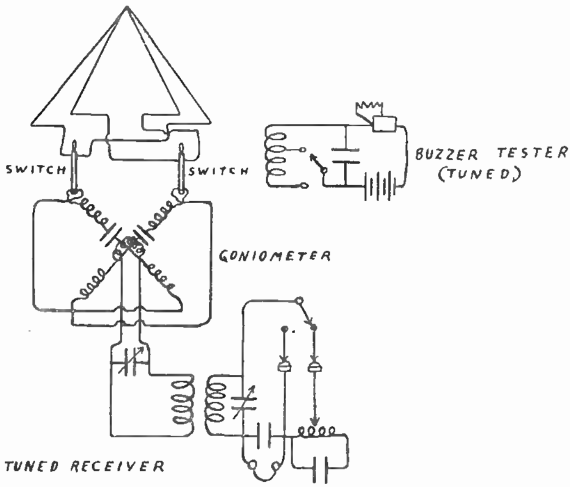


Fig. 616 Early Marconi Direction Finder. (Bucher.)

meter was practically the same as the result obtained with the Bellini-Tossi apparatus, using the strength of the signals heard in the telephone receivers as an indication of the direction of the waves instead of the spark in the antenna-ground wire. The Marconi direction finder also employed an angle divider with a regular compass dial.

Fig. 617. Marconi Goniometer.

510. It remained for Dr. F. A. Kolster, of the U. S. Bureau of Standards, Washington, D. C., to evolve the radio direction finder which is in practical use today. This was developed during the World War, and the details were kept secret at first. The Kolster direction finder is built on a different principle from previous types. It consists of a simple loop antenna, composed of several turns of wire wound around a wooden frame, usually about 4½ feet square, mounted so that it can be rotated, and having its case rigidly fastened to a pole which runs through the center of a circle marked off in degrees. A pointer on

the shaft indicates degrees of the circle as the loop is rotated. The loop illustrated in figure 618a makes contact

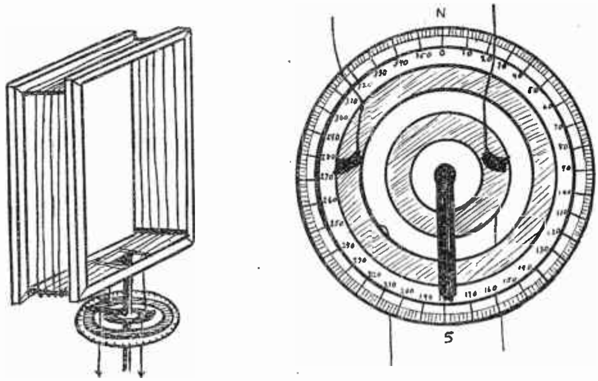


Fig. 618a. Direction-Finder Loop, Showing Slipping Contacts.

with a vacuum-tube receiving apparatus through slipping brushes which rest on two brass rings insulated from each other. In some models other arrangements have been made

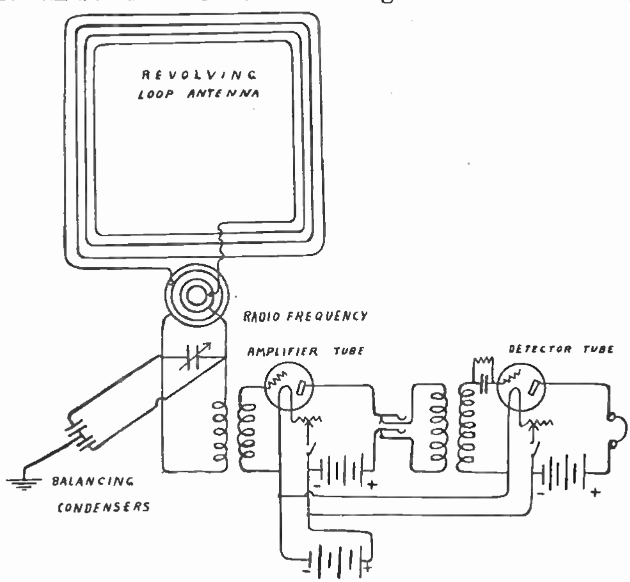


Fig. 618b. Circuit Diagram of Kolster Radio Compass.

for obtaining a rotating contact between the loop and the receiving apparatus. The latter must have at least one stage of radio-frequency amplification, and usually has three stages. If used with radio-frequency, and audio-frequency amplification, it can be operated with a loud speaker, which is much more convenient for the operator than being obliged to keep the head phones on.

511. There are two methods of using the compass loop, known as the *bilateral* and the *unilateral* methods. The bilateral method consists of finding the direction of the oncoming electric waves by turning the loop until the signals in the telephone are a minimum, or silent, due to the opposing polarity of the energy picked up by each side of the loop. The position of maximum signals covers a much wider turning position of the loop. The minimum is exactly at right angles to the direction of the received waves. Each has the disadvantage of being bilateral, or of indicating either one of two points exactly opposite each other. Usually the operator has sufficient idea of his whereabouts to know that the signals could be coming from only one of the two directions indicated, but this is not always the case, and when this point is uncertain the unidirectional method is used to determine the approximate direction of the signals, after which a sharper tuning in this direction is obtained by use of the minimum tuning method. The unidirectional direction finding is accomplished by using the loop in conjunction with the regular elevated antenna. It is based on the *polarity* phase of the loop. When the loop is turned in such a position that the signals are loudest in the telephones, in the bilateral method, the loop is standing parallel to the direction from which the signals are being transmitted, and the question is to know from which side of the

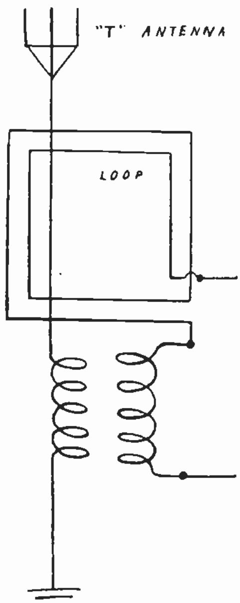


Fig. 619. Fundamental Idea of Unilateral Direction Finding.

coil they are coming. If the loop is turned completely around, the signals are as loud as before. However, in turning the loop around and receiving the signals again at maximum strength, the *direction of the current in the loop is reversed*. In other words, *the polarity of loop* is reversed. In the *bilateral* method this fact is made no practical use of, but it is the foundation of the *unilateral* method. By inductively coupling the loop antenna to the elevated antenna, so that some of the received energy of the antenna is conveyed to the loop, we have a means of taking advantage of this. When the current of the antenna circuit is superimposed upon the current picked up by the loop itself, the current in the loop is affected according to the relative polarity of the antenna current and the loop current. When the loop is in such a position that the currents from both sources are flowing in the same direction, the signals heard in the receiving telephones will be louder than without the induced antenna current, but when the two currents oppose each other, turning the loop parallel with the oncoming waves will only produce very weak signals. This is because the antenna current does not reverse with the reversal of the loop. By this method the approximate direction of the transmitter can be learned, However, as the maximum signals cover a wider range of the compass dial than the minimum, this is never accurate, and the loop must then be disconnected from the antenna coupling, and used separately to determine the exact direction of the oncoming signals, by the method of tuning these signals out.

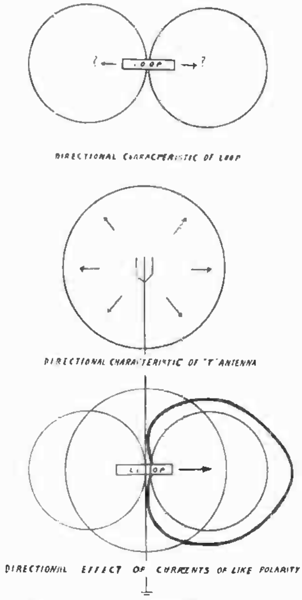


Fig. 620. Directional Effect of Loop and Antenna Current of Like Polarity.

The loop and antenna to be used for unidirectional radio compass work must be calibrated together, arranging a pointer on the shaft, which turns the loop in such a position that it indicates the direction of a *known* station when the

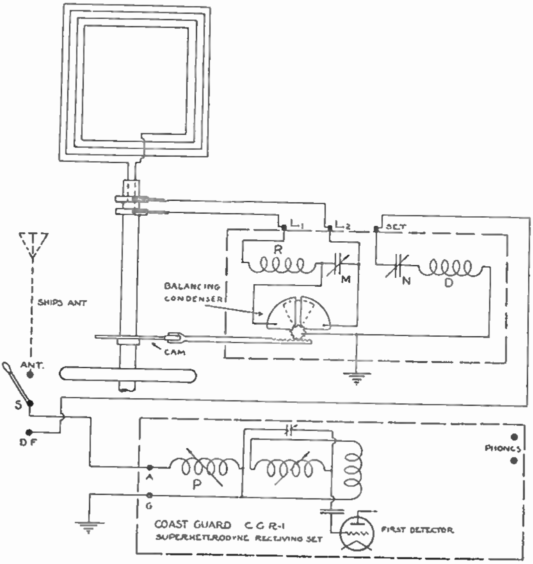


Fig. 621a. Unilateral Direction-Finding Apparatus.

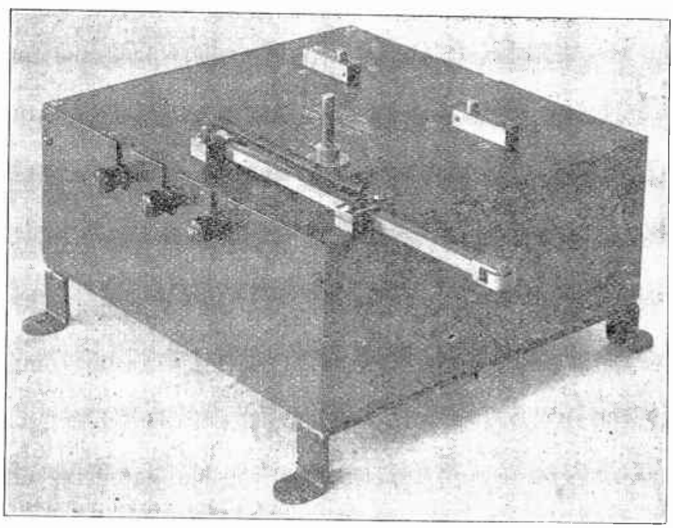


Fig. 621b. Direction-Finder Unit Used in U. S. Coast Guard

two antennæ give the loudest signals. After this, with the two used together and loudest signals heard, the pointer will show the direction from which the signals are coming. The amount of antenna current used can be controlled by varying the coupling. Too much antenna current will overcome the energy picked up by the loop, and it will be difficult to determine louder signals from one direction than from the opposite. The graph shown in figure 620 is called a *cardiac curve.*

Figure 621a is a diagram of a direction-finding apparatus that has been developed for the U. S. Coast Guard. It operates in conjunction with the superheterodyne receiver CGR-1, described in chapter 37. The direction-finder coil is over the pilot house, and is 20 inches square, being composed of 4 turns of heavy ignition cable. The balancing condenser is operated by means of a cam on the direction-finding chart, instead of by hand as has previously been customary. The direction-finder coil is coupled to the receiving set through transformer RD. Switch S throws the superheterodyne either on the ship's antenna or the direction finder, so that one receiving set may be used for either purpose. Figure 621b is a photograph of the direction-finder unit, which is indicated inside of dotted lines in figure 621a. The cam can be seen directly in front.*

512. In practice, with the revolving loop mounted directly over a magnetic compass, and the magnetic needle of the latter pointing north, the degree of the circle removed from north, as indicated by a pointer arranged on the shaft supporting the loop in such a manner as to point at right angles to the turns of wire composing the loop, will show the direction of the transmitter from the receiving loop. In figure 622 the manner of determining the position of a ship at sea by this method is illustrated. If it is found that the ship is N 60° E from Cape Henry and S 70° E from Cape Charles, and a line is drawn on the chart, or a string with a weight at the end laid out, showing on the map these two directions carried in a straight line until they cross, the point where they cross is bound to be the position of the ship. The latitude and longitude may then be easily seen

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*See Scientific Paper of the Bureau of Standards, entitled *A Unicontrol High-Frequency Radio Direction Finder,* by F. W. Dunmore.

on the chart. It is sometimes found a convenience to obtain an additional check on this position by taking a bearing from a third point, such as Hog Island, in the accompanying illustration.

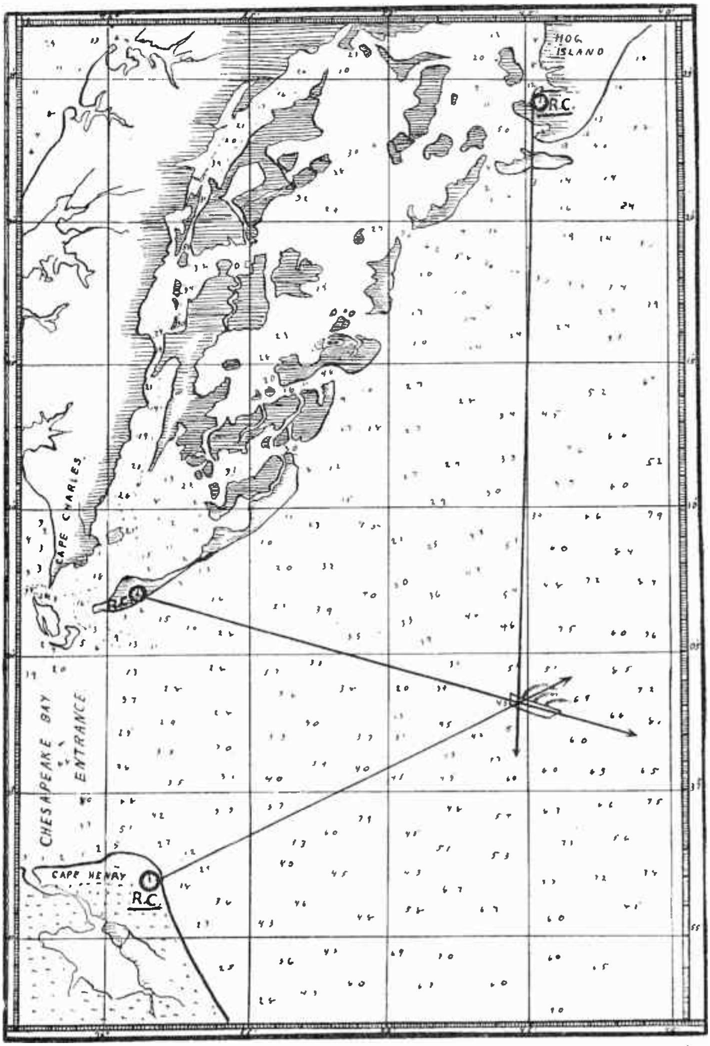


Fig. 622. Radio-Compass Bearings Showing Position of Ship Entering Chesapeake Bay.

The hull of a ship causes received electric waves to deviate slightly, this being the principal cause of errors. Hence it is necessary to calibrate each compass where it is to be used, keeping a memorandum, or *correction* curve.*

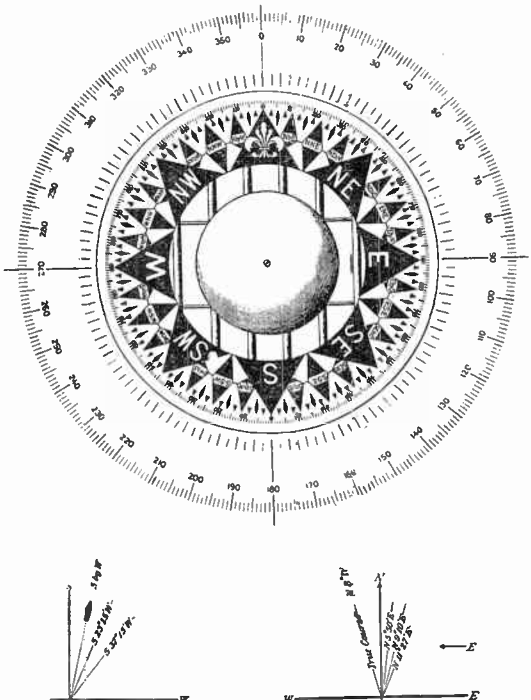


Fig. 623. Mariner's Compass Card, Placed Inside of Circle Marked Off in Degrees From Zero to 360, for Comparison.

The mariner's compass is marked off in four cardinal points, which are subdivided, as indicated in figure 623, into North East, East by North, South East by South, etc. Bearings are North by so many degrees East or West from this, and South by so many degrees East or West of South. There can be no more than ninety degrees in a nautical bearing of this kind. For some kinds of reckoning the regular degrees of the circle, clockwise from zero to 360 degrees, may also be used. It is the latter that are generally transmitted in radio direction finding.

*See sixth edition of *Robison's Manual of Radio Telegraphy and Telephony* for directions for making calibration and deviation correction curves.

513. Radio-compass direction finding in the merchant marine is frequently operated in a manner that might be called backwards. That is, it is necessary for the compass station on land to locate the direction of the ship, instead of the ship locating the direction of the shore station. The radio operator on board the vessel calls the radio-compass station, choosing from the list of such stations the one that he believes his ship to be nearest, sending their call letters three times de his letters three times. He then sends the call letters, *Q T E,* meaning: "What is my true bearing?" When the operator at the shore station receives this call he proceeds to turn his loop until he determines the direction of the ship. Meanwhile the operator is sending signals composed of his ship's call letters with the dashes prolonged, or whatever else the compass-station operator may request him to send. When the land compass-station operator has located the direction of the ship, he transmits this to the ship's operator. This gives the ship's master only one bearing. In some cases he is able to determine his position in latitude and longitude by means of this one radio-compass bearing used to check on his reckoning of the ship's direction of movement, from a known position at so many knots per hour. If he desires to have his position given to him, the radio operator may then obtain a bearing from another shore compass station, which the captain uses as a cross bearing to determine his position. Or, if desired, *a master compass station on shore will communicate with the two nearest shore stations with low-powered continuous waves, or by land line, asking them to take bearings on the ship simultaneously.* The ship's operator then sends his signals and the shore stations take their bearings at the same time. The assisting stations then send the result of this work to the master station. At this station the position of the ship may be plotted and sent to the ship's operator. However, as this places a great responsibility upon the shore station operator sending it, he may reserve the right to send to the ship only the bearings obtained from the three shore stations, and leave the determining of the exact position to the master of the ship. Master radio-compass stations are designated in a special list in the *Commercial Call Book.*

Compass shore stations now work in *calibrated sectors* of the circle, and sometimes refer an operator calling for bearings to another station in whose sector his ship would be located.

Occasionally it is necessary to repeat the direction-finding work a second time, but generally it is sufficiently accurate to locate the ship's position. If three bearings are obtained, and at the point of intersection a triangle is formed, covering sufficient space to indicate a distance of as much as half a mile within the triangle, the position is not safe and the work must be repeated.

The transmitting for radio-compass direction finding is done on a special wave length set aside for this purpose. At present this is 800 meters in the United States, including calling the compass station for QTE (450 foreign waters). As this has been changed several times and is subject to further changes, this wave length is not given as final. Operators at sea should keep informed on the subject.

514. The advantages of this method of finding bearings can be realized, as it can be used with sun and stars invisible for the usual astronomical observations, and when soundings may be uncertain. Dr. Kolster evolved a plan for equipping all lighthouse stations with automatic transmitters, operated by motors or clockwork, which on 1,000 meters transmit the station's call letters or special signals

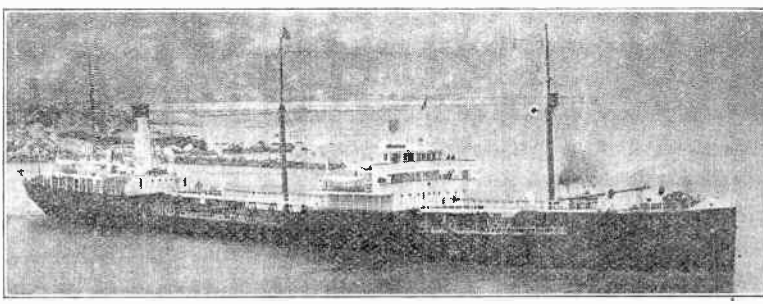


Fig. 624. The S. S. Emidio, of the General Petroleum Corporation, Equipped With Kolster Direction-Finding Compass Loop.

at regular intervals. With a compass loop located on board, a mariner can at any time determine his position from these *radio beacons*. This means more to the navigator than the lighthouses themselves, because the beacons can be heard when the lights cannot be seen. Radio beacons are now installed at several points along the United States coast, in lighthouses, at harbor entrances and off dangerous coasts, and are gradually being increased in number. The Ambrose Channel Light Ship in New York harbor was the first radio beacon in the world and has been in active operation since its installation. The beacons send out their guiding signals during the night, and in the daytime during storms or foggy weather. By giving each beacon a different group of dots and dashes, such as . . . ––––, –––– . ––––, . . –– . . ––, etc., its particular "voice" can be distinguished from all other signals which may be heard at the same time. This recognition is made still easier, and interference between beacons overcome, by staggering the distance between the signals used within range of each other. In some cases, more frequently for communication with airplanes than with ships, the beacon sends in a directional beam, using the reflector described in paragraph 357. Beacon operators will also assist an operator at sea by transmitting on 800 meters if requested to do so.

The original beacon stations were equipped with spark

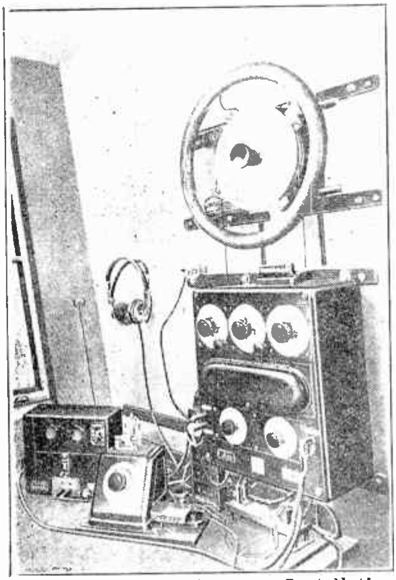


Fig. 625a. Radio Compass Installation on the Dirigible Los Angeles. (Photograph furnished by the Telefunken Co. of Berlin.)

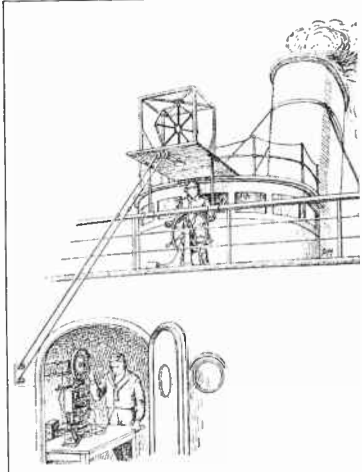


Fig. 625b. German Method of Controlling Radio-Compass Loop on Board Ship.

transmitters; but over one-half of these have been replaced with vacuum-tube apparatus using the full-wave self rectifying circuit with a 500-cycle a.c. supply. The maximum power output of these is about 500 watts, and the dependable distance range about 300 miles, although reports of successful use of the beacons over a distance of 1000 miles are not uncommon.

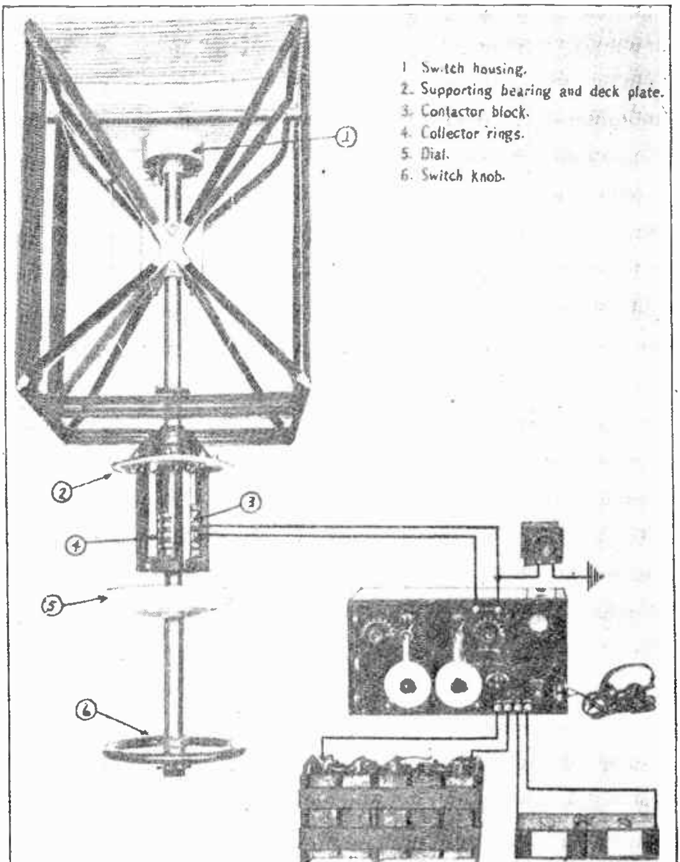


Fig. 626a. Type of Radio Compass used in the U. S. Navy. (Robinson's Manual.)

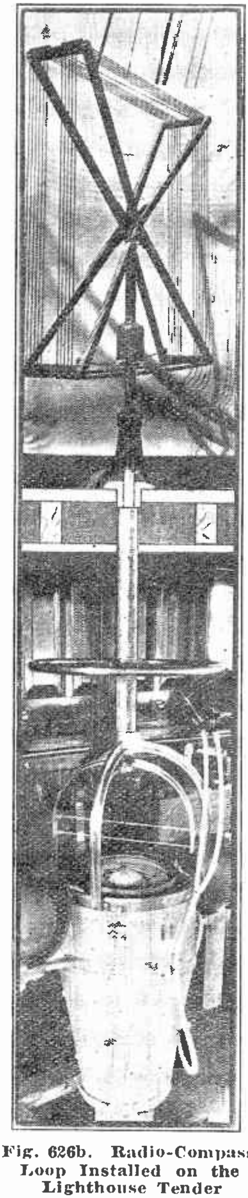


Fig. 626b. Radio-Compass Loop Installed on the Lighthouse Tender Tulip.

In the Navy many of the vessels have compass loops permanently installed as a part of their radio equipment, and the majority of the Navy receiving sets have two extra binding posts on the panel, intended for connecting the compass loop. If the loop is not used, these posts are shorted by a small strip of metal.

In figure 625b is shown the German method of operating the radio-compass loop. It can be seen that the loop is rotated by means of a cable and pulley which do not form a part of the electrical connection. A photograph of the same apparatus is shown in figure 625a, where it is shown installed in the German-built Zeppelin ZRIII, which was purchased by the United States and rechristened the Los Angeles.

A modern radio-compass outfit installed on the Lighthouse Tender Tulip is shown in figure 626b. In this two taut wires are mounted at the base of the revolving shaft, and directly over the magnetic compass. Readings are taken by sighting down on these two wires until only one wire is visible. In some models of the Kolster compass the receiving set is installed inside the base, under the magnetic compass. There is a small door which may be closed when the set is not in use. (See paragraph 26 for mariner's compass.)

The compass loop is usually mounted over the pilot house. It may be handled by the ship's master, after his having ordered the radio operator to ask the shore station for signals, in case they are not sending the automatic signals, or if it is desired to work on 800 meters. Or the captain may have the operator come and assist him.

When the direction-finding work is finished it is necessary to inform the compass station, if they have been transmitting by request, so that they may stop sending.

515. The bulletins of the Bureau of Navigation, Department of Commerce, give information concerning radio-compass stations installed on the United States coasts. Among the stations which are now in operation, ready to reply to calls from ships, are Boston, New York, Delaware Capes, Chesapeake Capes, Gloucester, Mass.; Deer Island, Mass.; Fire Island, N. Y.; Rockaway Beach, Long Island; Cape May, New Jersey; Cape Henlopen, Delaware, etc. The Department of Commerce has given out the following information for operators: "To obtain a bearing from independent radio-compass stations, call the station from which the bearing is desired in the usual manner and request bearings by means of a conventional signal given below. Simultaneous bearings from two or more compass stations can be obtained by making the call include the other compass stations desired. To obtain bearings from harbor-entrance compass stations carry out the same procedure with the exception that the compass-control station should be called instead of the compass station. When bearings are requested simultaneously from two or more compass stations, the compass station which is farthest north will supply the ship with its bearing first, the others will then follow in the order of their north to south, or east to west geographical location. The following abbreviated signals will be used until further notice:

Signal	Meaning
QTE?...............	What is my true bearing?
QTE................	Your true bearing is.................degrees from..................radio compass station.
QTF?...............	What is my position?
QTF................	Your position is latitude............, longitude ....

The radio-compass station (or compass-control station for harbor-entrance compass stations) will answer requests for bearings and positions in the customary manner of answering calls and follow their call letters with 'K' if they desire to take a bearing at that time, 'QRX' if they desire to stand by, or other abbreviated signals authorized by international regulations. On being told to "K," vessels desiring bearings or positions will transmit their radio call letters for 30 seconds, and then make dashes for one minute, making their call letters three times and terminating with the conventional signal 'K' (go ahead). At the expiration of the direction-determining signals the radio-compass station (or compass-control station) will call the vessel, make 'QTE' and send the bearing in degrees, and the name of the compass station which obtained the bearing, or 'QTF' and the position in latitude and longitude. Bearings and positions will always be transmitted in *words* to avoid error. Vessels *acknowledge* receipt of positions or bearings by making the call letters of the station transmitting the bearing or position once, 'de' vessel's call letters, and *then repeat the bearing or position received, using numerals.*" In this country radio-compass bearings are not charged for. In some European countries a charge is made for the service.

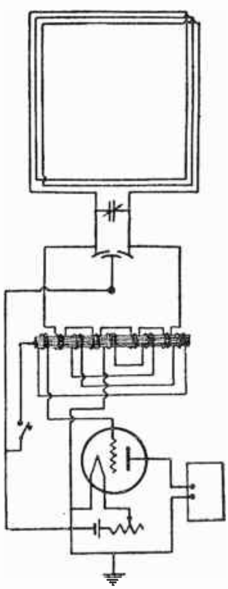


Fig. 627. Radio-Compass Apparatus Patented by F. W. Dunmore.

516. When obtaining a bearing on board ship, the antenna should be grounded, and the compass loop be as far as possible from guy wires, etc. The leads between the receiving apparatus and the compass loop should be as short as possible, even the battery leads being as short as practical. If the radio operating room has metallic walls, the whole apparatus should be moved outside if possible, or at least the loop must be outside of the metal walls, which might act as a magnetic shield, shutting off the signals from the loop. Mr. F. W. Dunmore, co-worker with Dr. Kolster at the Bureau of Standards in developing the present type of radio

compass, says: "The distortion of the radio waves due to the ship's mass may introduce an error of from 10 to 20 degrees. This error will be a maximum when the transmitting station lies on a line at 45 degrees to the ship's center line. With the signal coming from fore, aft, starboard or port, the wave distortion is practically zero. When more accurate bearings are required, therefore, *the ship should be turned so that the wave will approach the ship from any one of these directions.* In cases where the radio compass is a permanent installation, such as the one on the Lighthouse Tender Tulip, a scale and

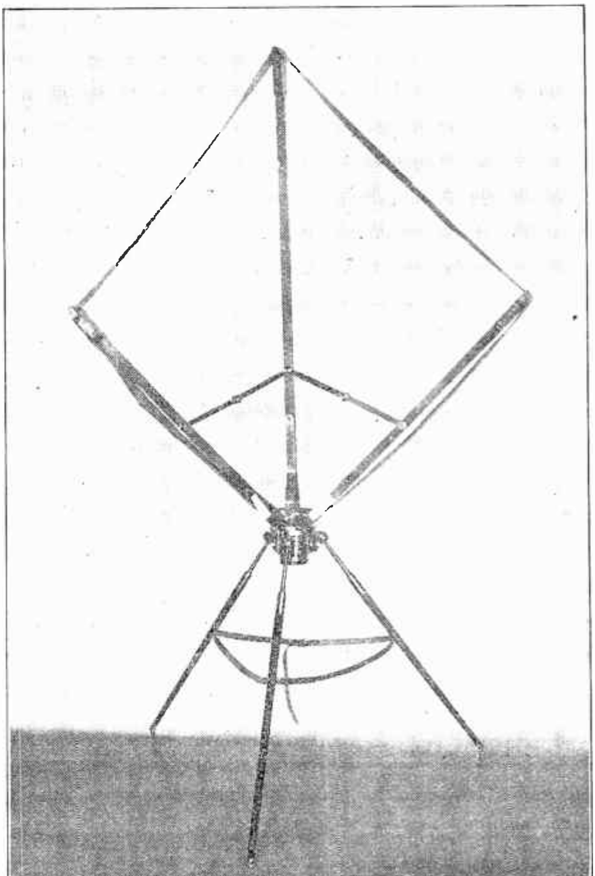


Fig. 628. Portable Loop and Magnetic Compass Which Saw Service in the Army During the World War.

pointer are provided and the bearings read in degrees. In this type of installation the radio compass is calibrated so that corrections may be made for the effect of the ship in distorting the wave." Mr. Dunmore has recently patented and "dedicated to the public, who may use it without payment of royalties," an addition to the loop direction finder, as shown in figure 627. This consists of the use of a transformer with a laminated iron core, the effect of which is to make the loop more sharply directional, and to reduce disturbing noises from motors, etc., "bypassing" them to the earth.

517. The radio compass is not confined to maritime work. Portable collapsible loops were used extensively during the World War, both for directional transmitting and receiving over short ranges on short wave lengths, and with limited power, and for direction finding in conjunction with magnetic compasses. On airplanes in both the Army and the Navy, compass loops are considered indispensable, and are often used in steering the craft when high in the air. On account of the noise from the engine, certain adaptations are necessary. The minimum point is impossible to determine, so loudest signals, with the loop turned parallel with the transmitted waves must be used. Also, every inch of space is valuable, and rotating of the loop is sometimes inconvenient for the operator. Two loops are frequently used, and in some cases these are rigidly mounted between the struts of the machine and the wings. When thus fastened, it is necessary to turn the whole machine around in order to turn the loop. When the purpose of the compass loops is to guide an airplane to and from its hangar, or base radio station, this arrangement serves to keep the machine headed in the right direction. Another method employs two smaller loops mounted at right angles to each other, on a common shaft, which may be rotated. These are usually installed in the fuselage, and can be used to locate a station without turning the plane. A switch is arranged so that the operator on the airplane can connect the receiver to first one of the loops and then the other. The ground station is in a line parallel to the loop from which loud signals are heard. If weak signals are heard in the coil at right angles to the one in which loud signals are heard, the latter is not turned exactly in line with the ground station. Thus the right angle coil is used to check the other one. Planes equipped with compass loops have been enabled to fly in a "bee-line" to ships at sea.

518. Loops used for radio-compass direction finding are carefully designed for the wave-length range on which they are to be used, and the condensers chosen for the corresponding capacity. All tuning of the receiver must be done off the minimum position of the loop, and the compensating condenser must be carefully adjusted as the coil is rotated. Quoting from *Robison's Manual,* "The presence of the antenna effect and the use of an artificial capacity balance makes it necessary to use extreme care in tuning the circuit, because any adjustment of the compensating condenser will disturb the wave length of the circuit. This change in wave length, or detuning from resonance with the incoming signal, causes a shift in the position of the minimum, thereby giving rise to an error in the determination of direction."

A small loop with several turns of wire will generally give louder signals than a larger one with fewer turns. But as the inductance and capacity are increased by increasing the number of turns in the loop, the smaller number of turns will be best suited for receiving short wave lengths, and the greater number for receiving longer wave lengths. A coil 8 feet square, made of three turns of wire, would have a fundamental wave length of about 160 meters, while a coil 3 feet square having 8 turns would have about 183 meters for its fundamental. A coil 5 feet square, composed of eight turns of No. 22 insulated copper wire, one-half inch apart, is the type often used on ships. When connected across a .0007 micromicrofarad variable condenser, this will tune to from 400 to 800 meters. With a .0015 micromicrofarad condenser, it will respond to 1,000 meters. The latter wave length may also be obtained by using 12 turns of wire and a .0007 micromicrofarad condenser. The loop is grounded through the capacity between itself and the earth, hence its height above the earth affects its wave length.

519. In using the direction-finding loop for navigating a vessel at sea, it is necessary to take precautions against error on the chart, as the line obtained by the bearing is not a straight line, as compared to the chart, but a curve. Only from the meridian would the line be straight. It is frequently found convenient to compare bearings obtained by radio-compass direction fiinding with bearings obtained by dead reckoning. The radio operator going to sea is referred to the many books devoted exclusively to navigation (Names of some are included in the bibliograph in the appendix of this book.)

TABLE OF APPROXIMATE WAVE LENGTH RANGE OF LOOP ANTENNÆ

(Bureau of Standards)

Coil, 5 feet square, spacing of turns in each case, one-half inch. Using variable condenser having maximum capacity 0.00065 microfarad, minimum capacity 0.00002 microfarad.

With 4 turns........ $\lambda = 300$ to 400 meters
With 8 turns........ $\lambda = 350$ to 700 meters
With 16 turns........ $\lambda = 500$ to 1,000 meters

Coil, 5 feet square, spacing of turns one-half inch. Using variable condenser having maximum capacity 0.00140 microfarad, minimum 0.000045 microfarad,

With 4 turns........ $\lambda = 380$ to 850 meters
With 8 turns........ $\lambda = 400$ to 950 meters
With 16 turns........ $\lambda = 675$ to 2,300 meters

Coil, 4 feet square. Four turns, space one inch. Using variable condenser having maximum capacity 0.00140 microfarad minimum 0.000045 microfarad,

$\lambda = 180$ to 500 meters

Coil, 4 feet square. Four turns, spaced one inch. Using variable condenser having maximum capacity 0.00060 microfarad, minimum 0.00002 microfarad,

$\lambda = 150$ to 350 meters

Coil, 4 feet square, 100 turns wound in 5 groups of 20 turns each in five slots, distance between slots one-quarter inch. Range approximately 6,000 to 15,000 meters.*

520. A French aviator, W. A. Loth, has been decorated with the "Prix de Navigation" for his patented system of guiding either vessels or airplanes to port, or over any prearranged route, in the dark of night or during fog. This system consists of the use of three or four large flat inductance coils, mounted at different angles on the ship or airplane. The prearranged course is marked out by a submerged cable, with the end left open, and this cable is charged with alternating current of high voltage. The theory is that the alternating current returns to its source through the earth, thus setting up alternations above the earth, to

*See *Scientific Paper of Bureau of Standards, No.* 354, for data on coil antennae. Also *Scientific Paper No.* 428, the *Radio Direction Finder and Its Application to Navigation,* by Frederick A. Kolster and Francis W. Dunmore, for navigation by radio compass, and *Scientific Paper No.* 480, *A Directive Type of Radio Beacon and Its Application to Navigation,* by F. H. Engel and F. W. Dunmore, for further information on beacons.

which the coils respond, according to their plane. By using the coils mounted at different angles, with different planes, it is possible for the operator to tell exactly his relation to the submerged charged cable, and thus to be guided safely to his base.

521. Closely related to the radio compass, and useful as a means of checking on radio-compass bearings is the *sonic depth finder,* which has been developed by the engineering department of the U. S. Navy, in Washington, D. C. This device has proved quite as important in navigation as the radio compass and it is stated by the personnel of the Naval Research Laboratory that it will be included in the equipment of all vessels of the merchant marine in the future, and that a knowledge of its operation will be required of the practical radio operator.

The following article on the sonic depth finder was prepared for this book by Oscar E. Dudley, Associate Radio Engineer, U. S. N., who has been actively engaged in the development of the apparatus.

THE SONIC DEPTH FINDER

Summary

The Sonic Depth Finder is a device used for determining the depth of water by means of sound waves. It operates in accordance with the law that the distance a sound wave travels in a uniform medium in a given time is equal to the product of the time interval and the velocity of the sound wave. In principle it is a connecting link between a sensitive type of sound receiver and a sound transmitter of the oscillator type, which serves to measure the time required for sound signals to travel from the transmitter to the reflecting surface and back to the receiver. It is a simple rugged piece of apparatus that only requires ordinary care and which can be quickly and easily calibrated or checked for accuracy by means of a stop-watch.

Description

Mechanical. The mechanical construction of the sonic depth finder can be understood in principle by referring to Fig. A, wherein each member is designated by a numeral. A cam wheel, 1, is driven at uniform speed by means of a constant speed motor, 2, controlled by a governor, 16. Three is a switch secured to the frame, the arm of which rides on the rotating cam 1. Four is a switch secured to the rotating wheel 5; this arm also rides on the rotating cam 1. The rotating wheel 5 carries a scale calibrated in fathoms, from 0 to 500, and is connected by means of gears to the hand wheel 6.

Electrical. Fig. A also shows a schematic diagram of the electrical circuits employed in the sonic depth finder. By means of the switch 7 the motor circuit is closed and cam wheel 1 is rotated at constant speed. The oscillator (13) field is also excited through the series resistance 16. When switch 23 is closed switch arm 3 falls into the slot on the cam wheel 1 and closes the circuit of relay 8, which is connected to the 110 volt D. C. circuit, once every revolution. The relay 8 when excited closes the A. C. circuit through the oscillator 13 armature and alternator 15. No. 11 is a hand key in shunt with the switch 3 for operating the relay by hand. Switch 4 closes a circuit taken off the alternator 15, in which a variable resistance 17, a condenser 9 and an inductance coil 20 are in series. The coil 10 inductively coupled to coil 20, and variable, is connected through the two-position switch 12 to the terminals C and R, which are in turn connected to the phone R. No. 18 represents two transformers, the secondaries of which are connected through the switch 12 to the phone L. The primaries of this transformer are each connected in series with a battery 19, switch

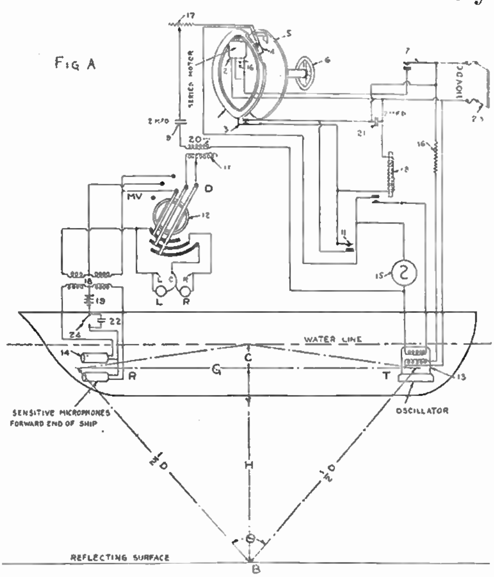


Fig. 629a. Schematic Wiring Diagram of Sonic Depth Finder.

24 shunted with the condenser 22 and one of the sensitive microphones at 14. No. 21 is a condenser shunted across the relay circuit. Switch 12 when placed in the opposite position from that shown connects the output from one microphone to the left phone and the other microphone to the right phone. Usually the microphones are placed on opposite sides of the vessel near the bow and the outputs taken through a compensator, so that with the switch in this position the direction of lightship bells, echoes and other shipping noises may be obtained.

The device described may be regarded as an automatic signaling key designed to send out two separate equally timed signals of the character of short dashes and provided with a means of continuously varying the period between these two signals from 0 to a maximum equal to the period of the rotating cam.

Principle of Operation

General. The operation of the sonic depth finder is dependent upon the general physical law stated by the equation:

(Equation I) $D = V.T$

Where D represents the distance any mass or disturbance moving with a constant velocity V travels in time T. This equation, which gives the relation between time, velocity and distance for all physical displacements involving uniform velocity, is of wide application, since by its aid any one of the three factors can be determined if the other two are known.

Application. Since the velocity of sound waves through any sound-conducting medium is equal to the square root of the elasticity of the medium divided by its density, the velocity will be constant and determinable if the medium is homogenous and the above equation can be used to calculate the distance between two points in the medium by measuring the time required for a sound signal to travel from one point to the other. The equation also serves for computing the velocity of sound in any uniform medium if the time of sound transit between two points is measured and the distance between the two points is determined by triangulation or direct measurement.

Accuracy. The application of the above equation for determining distance by means of sound waves, though simple in theory, has proved difficult in practice because of the high velocity of such waves, especially in liquids and solids. A consideration of the equation shows that the error made in determining the distance D is equal to V times the error made in measuring T, and since V is large, T must be measured with extreme accuracy in order to determine D with a fair degree of accuracy. Stop-watch methods are too inaccurate and too much subject to the personal equation of the operator, and of the numerous other methods that have been devised all have employed apparatus too delicate or too involved to be practical. The sonic depth finder determines the factor T with a high degree of accuracy by measuring accurately p, the period between the outgoing signal and a dummy signal, and then adjusting the value of p so that it is a known function of T.

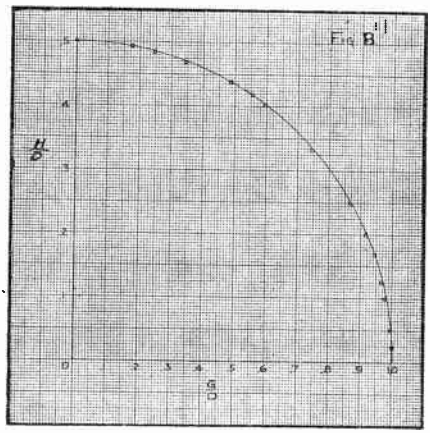


Fig. 629b. Correction Curve for Determining True Depth "H."

Determination of p.

(Equation II)

$$p = \frac{360}{S} \times R$$

S being the angular position of contact switch 4 with respect to the contact switch 3, and R the period of the cam wheel 1.

Relation between p and T. The relation between p and T becomes simple and determinate when the value S is so adjusted that the dummy signal is heard in one phone at the same instant that an incoming reflected signal is heard in the other phone or, in other words, when the adjustment of S is such that the transmission of the dummy signal and the reception of the reflected signal are synchronized or made coincident. Then T, the time required for the signal to travel from the transmitter to the reflecting surface and back to the receiver, is equal to 1, 2, 3, or some whole number N times R, the period of the cam wheel, plus p, the period between the outgoing signals and the dummy signals, and we have the relation:

(Equation III) $T = (N.R)$ plus p

and by substituting in equation I the value of T as determined by equation II and III, we have the relation:

(Equation IV) $D = (N.R + p)\ V$

It is to be noted that all the factors on the right-hand side of this equation are known with the exception of N, which is only known to be a whole number. In equation IV, D equals the total distance the sound has traveled to the reflecting surface or sea bottom and back to the receiver. For sounding the equation would then be:

(Equation V) $\text{Depth or } H = \dfrac{(N.R + p)\ V}{2}$

Determination of N. A consideration of equation 3 shows that N is the number of signals that are sent out *before* the first signal of the series reaches the receiver; or N may be defined as the number of the previous signal that is heard coincident with each dummy signal; i. e., as the first, second, third, or Nth signal previous to the one that is being transmitted. In the light of this definition it will be seen that the value of N can be determined in several ways. Two reliable methods are as follows:

(a) By means of the hand-signaling key 11 and a stop-watch determine the time interval, T, between the sending and receipt of a signal. Since N is known to be a whole number, the value of T will be sufficiently accurate to determine N through the relation:

$$T = (N.R) \text{ plus } p.$$

(b) Open the sonic depth finder signaling circuits with switch 7 until no signals or echoes are heard. Then close this circuit and count the number of signals sent out before the first one is heard in the phone L of the microphone circuit. This number, *not counting the first signal sent out,* gives the value of N.

Note: In practice, then, the depth finder should be adjusted for coincidence of sounds in the two phones. The scale reading then gives the value of p to use in the sounding equations 5. Then if by using the method b for determining the value of N it is found that the first signal sent out is heard before the second signal is transmitted N is less than one, therefore T is equal to p, and H would equal

$$\frac{p\,V}{2}$$

If the first echo is heard in coincidence with the second signal sent out then the value of N would be one and the scale would read the maximum value for p. Again, if the first echo is heard after the second signal is sent out but before the third signal, then the value of N would be one plus and would mean that the depth would be equal to

$$\frac{(R \text{ plus } p)\,V}{2}$$

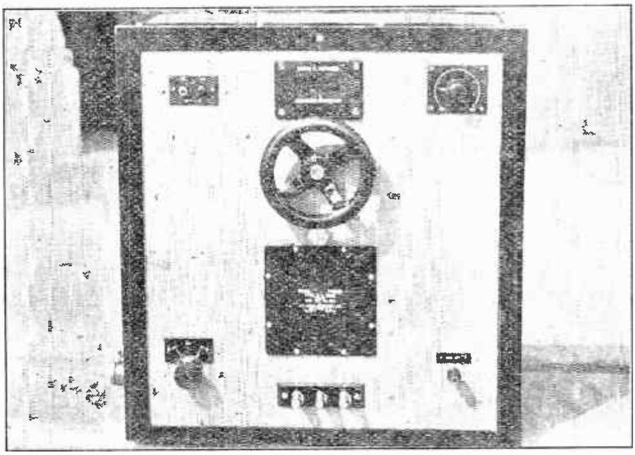
when coincidence was determined.

Correction of Depths. Depth as determined by the sonic depth finder is not the true depth, as can readily be seen by the diagram in Fig. A, for D is equal to the two sides of the triangle R.B.T., while H the depth is the bisector of the triangle. A method for correcting the value of D to give the true depth H can be understood in connection with Fig. A. This method is accurate if the sea-bottom is horizontal and is sufficiently accurate for practical purposes in most regions. For making this error clear the following equation is used:

(Equation VI)

$$\frac{H}{D} = \frac{1}{2}\sqrt{1 - \left(\frac{G}{D}\right)^2}$$

when G is the distance between the transmitter T and receiver R. But it must be remembered that this equation is not rigorously true except when the reflecting surface is



629c. Sonic Depth Finder Type SE-2242.

parallel with a straight line determined by T and R, Fig. A, or, in other words, when the triangle determined by T, R and the point of reflection is isosceles. If, however, the value of G be made zero, the sides of the triangle T and R become coincident and the equation then holds true no matter what slope the reflecting surface may have with respect to the horizontal. Under such conditions equation VI reduces to the simple form:

(Equation VII) $$H = \frac{D}{2}$$

and the reflecting surface is then normal to the direction of the received echo. In can be shown, however, that equation VI is sufficiently accurate for practical purposes provided the value of G is small with respect to D and, in order that the direct sound from the transmitter should not be received with too great intensity, the transmitter and receiver are usually mounted at opposite ends of a vessel. The curve shown in Fig. B has for ordinates the ratio H/D and for abscissas the ratio G/D and can be used for correcting the depth finder data. An inspection of this curve shows that H, the distance to the reflecting surface, differs by less than one per cent. from D/2, when the value of G, the separation of receiver and transmitter, is less than about 1.5 per cent.

of D as determined by the sonic depth finder. The value of G is usually not greater than 50 fathoms and, therefore, equation VII holds with sufficient accuracy for depths greater than about 100 fathoms.

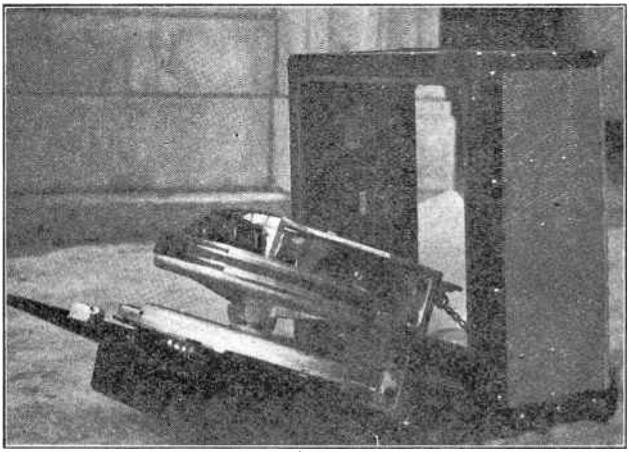


Fig. 629d. Side View of Depth Finder.

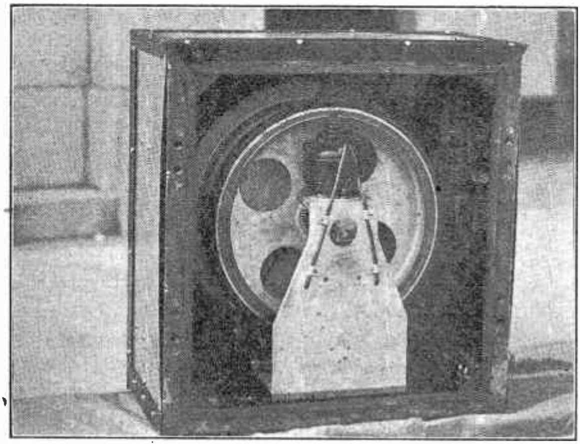


Fig. 629e. Back View of Depth Finder.

Sonic Depth Finder, Type SE-2242. In the preceding paragraphs the principle of operation of the sonic depth finder has been explained and the "sounding equation," in accordance with which it operates, has been developed in general terms. This will give the correct depth from the transmitter or receiver to the bottom. To this should be added C, in Fig. A, the distance from the transmitter or receiver to the surface of the water. The Type SE-2242 device, which was developed by the Naval Research Laboratory at Bellevue, Anacostia, D. C., principally for navigational purposes, requires the following values for the constants in the sounding equation:

(a) R, period of revolution of the cam—1¼ seconds.

(b) V, average velocity of sound in sea water—4,800 feet per second.

The sounding equation has been worked out and the scale on 5 in Fig. A has been calibrated to read direct in fathoms up to 500, so that all the operator has to do is make sure that R, the period of the cam wheel, is of the correct value, determine N, synchronize the signals and, depending on the value of N, either read the scale direct in fathoms or add N times the maximum scale reading to reading obtained when the signals are coincident. If the depth is less than 100 fathoms add the correction obtained from the correction chart, Fig. B.

Velocity of Sound. The velocity of sound in sea water depends upon the temperature, pressure and salinity of the water. From such experimental data as is at present available the value 4,800 feet per second is a fair average. There is very little experimental data showing the effect of temperature, pressure, or salinity on the velocity of sound, but the sonic depth finder itself will doubtless serve as a means for collecting such data as will lead to an expression of the velocity V in terms of these three variables.

Where used and by whom operated. The sonic depth finder will soon be installed on all seagoing vessels of the first and second class and will be used for navigational purposes. As a safeguard to navigation it is unexcelled, for no matter what speed the vessel is making the *depth of water* can be readily determined at all times. Radio compass bearings, which sometimes are very confusing, may be checked with the sonic depth finder by obtaining the depth and comparing it with charted depth at the positions given by the compass bearing. The compass position checking with the depth can be relied upon as being the true bearing. When approaching shore at night or in the fog, shoal water can readily be detected and the approximate position can be determined. If a ledge, bank or plateau is shown on the chart in the vessel's course, the time of crossing either or all of these can readily be determined by the sonic depth finder and give an accurate check on the dead reckoning.

The sonic depth finders are usually located in the radio room and are operated and cared for by the radio operators.

Operating Procedure. The procedure to be followed when operating the sonic depth finder in general is as follows:

(a) Close the battery switch 24 of the receiver.

(b) Close main switch 23 and start the alternator 15.

(c) Start the motor by closing the switch 7. Check the period R of the rotating cam 1 by timing several revolutions with a stop-watch. If the period R is not correct, adjust the governor 16.

(d) Set the switch 12 in position D. Listen in on the phones L and R and slowly rotate the hand wheel until the dummy signal in the right phone is synchronized or made coincident with the echo or reflected signal in the left phone. Note the scale reading and then open the switch 7, thereby stopping the motor 2.

(e) Send out a short dash by pressing the hand key 11, and with a stop-watch determine the time T for the reflected signal to reach the receiver. Determine the value of N and

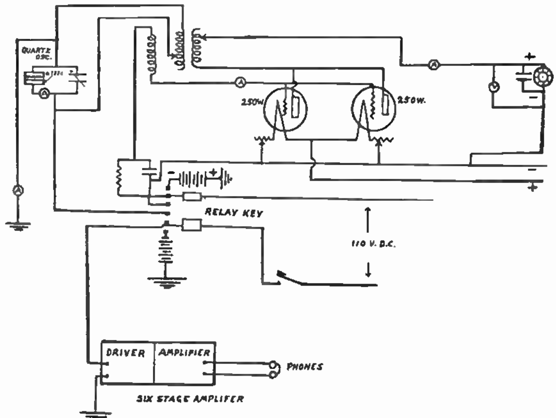


Fig. 630. Circuit Diagram of Super-Sonic Transmitter and Receiving Apparatus.

apply to the scale reading. If N is less than one, read direct in fathoms.

522. The *super-sonic* oscillator, developed by the U. S. Naval Research Laboratory from a discovery of Prof. Langevin, of Paris, France, has great military value in detecting submarines, etc., by reflection. In peace, it can be used to advantage in taking depth soundings, and in underwater telegraphy and telephony. The apparatus consists of a mosaic of quartz crystal secured between two steel plates, used in connection with ordinary vacuum-tube radio apparatus. By applying high-voltage to one side of the quartz-crystal condenser, and exposing the other side to the water, the electrical oscillations are transformed into elastic mechanical vibrations which travel as waves of compression through water in a beam. The frequency used is above 30,000, hence its name of super-sonic. When mechanical vibrations of the same frequency come through the water and strike the outside steel plate, the quartz is compressed, and mechanical vibrations are set up, which in turn can be used to produce electrical oscillations, and the same quartz device serves as both transmitter and receiver.

CHAPTER 43

The Duties of the Practical Radio Operator

Laws and Regulations—Penalties—Commercial Wave Lengths—Relaying—Sending Money By Radio—SOS—Routing of Message—CQ—Power Near Shore Station—Intercommunication Law—Cable Count—Sample Message—Transmitted and Received Message Form—Abstract Sheet—Station Report—Log—Press—International Abbreviations — Blinker — Land-line and International Rate Sheets—Special Prefixes—Traffic Procedure—Rules for Operators—Ships' Inventory—Operator's Bond—Greenwich Time—Requirements for Position on Passenger Ship—Operator's Licenses—Medical Service Message.

523. Speaking generally, the work of a commercial radio operator may be said to consist of transmitting and receiving messages; but there is a great variety of duties included under this heading. It has been made clear that the operator is responsible for the condition of the apparatus with which he is to send and receive these messages, including the auxiliary source of power. He is also responsible for the money which he handles in connection with his commercial message work; and there are laws regulating the manner of handling his messages, with severe penalties for breaking the same.

Obtaining a first-class commercial radio license is something which represents considerable study and effort, and it is a pity for an operator to lose his license and his prospects of positions in this line of work for which he has prepared, on account of carelessness, foolishness, or ignorance of the laws and regulations. Operators have lost their positions on account of their inefficiency as transmitters and receivers. Licenses have been revoked on account of the operator's indifference to the condition of his apparatus, or his inability to keep it in working order. However, the majority of revoked licenses have been on account of lack of knowledge of, or indifference to, the *laws and regulations.* Every prospective radio operator and person wishing to obtain or use a radio operator's license of any class, should possess a copy of *Radio Communication Laws of the United States,* obtainable at the Government Printing Office, Washington, D. C., for 15 cents, and become thoroughly familiar with its contents.

524. The following rules and penalties are some of the important points in the Ship Act of August 13, 1912:

(1) If an operator plays what he considers a practical joke, by sending out a *false distress call,* his punishment *will be five years in prison, or a fine of $2,500 or both.* Such a fraudulent call for help might cost the ship's company thousands of dollars on account of other vessels turning out of their course to come to the rescue.

(2) If he sends any *other fraudulent message,* or radiogram, he *will be fined $1,000, or two years in prison, or both.*

(3) If the operator sends out a broad interfering wave, on high power, with a spiteful knowledge that it will handicap the work of some other operator against whom he may have a grudge, for this *malicious interference* his *penalty will be one year in prison, or a fine of $500, or both.*

Neglect to stop and send QRM? frequently when testing, to ascertain that no one else is being inconvenienced by the testing, is also classed as malicious interference and punishable by the same penalty.

(4) If the operator *divulges the secrecy of messages* with which he is entrusted, the penalty will be *three months in prison,* or a fine of $250, or both.

(5) *Operators are not allowed to indulge in superfluous communications.* The narrations of radio inspectors, who have had the revoking of commercial radio licenses to handle, contain many instances of operators who have kept the air blue for hours with profane and unrepeatable language. It is hard to believe that any young man could be so indecent, or so dense, as to forget that his message carries to anyone within range who can listen and understand the code. The Government's way of handling such operators is to revoke their licenses and place their names on a list of undesirables in this field. For a minor offense in the way of communication which is not objectionable, *the operator is fined $25* and given another chance. *If he repeats the offense, he loses his license.*

(6) Any person or corporation within the jurisdiction of the United States who shall operate a radio station the signals from which may extend beyond the boundaries of the state, or which in any way could cause interference, without having the *station properly licensed,* is guilty of a misdemeanor, and may be punished by a fine not exceeding $500 and have his apparatus adjudged forfeited to the United States.

(7) It is unlawful to employ any *unlicensed person* or for

any unlicensed person to serve in charge or in supervision of the use and operation of such a station, and any person violating this provision shall be guilty of a misdemeanor, and be punished by a fine of not more than $100, or imprisonment for not more than two months, or both.

525. The wave lengths to be used in commercial work are designated by the Government. For several years these were 300 and 600 meters, or over 1,600 meters, from 600 to 1,600 meters being reserved for the Navy (450 meters for foreign communication). However, due to the many complaints received by the Department of Commerce from broadcast listeners regarding interference from ship stations operating on 300 meters, this wave length has been discarded. The *Radio Service Bulletin* of this department for May, 1925, states: "Radio stations of the United States are no longer being licensed to use 300 and 450 meters, except broadcasting stations. The 450 meter wave may be used, however, by ship stations in communicating with foreign compass stations. Foreign ship stations should not attempt to communicate with stations of this country on either 300 or 450 meter wave length." Other information given out by the Department of Commerce in May, 1925, states that ship stations should be equipped for wave lengths as shown in figure 476, or 600 meters, 706 meters, 800 for radio compass work, and 875 meters. All tube transmitters installed on vessels are equipped for sending on 875 meters, and it is expected that spark sets will immediately be arranged for using this wave length also. Navy vessels do not now use below 975 meters, except for communication with merchant ships. The operator should avoid use of any except the sharpest wave which he can obtain from his set, which must comply with the regulation for a *pure wave,* which states that *a second wave must not exceed one-tenth of the volume of the main wave.* Also, *the logarithmic decrement must not exceed .1.*

526. *Distress calls* always have precedence over all other forms of messages. If an operator, while on duty, should hear the S O S, he should immediately cease all regular communication which might interfere with the radio work of the ship in distress. He should learn the name of the calling ship and its location, then he should immediately notify the captain of his vessel. The case is then in the hands of the captain. The usual procedure is to call for other ships in the vicinity, undertake to learn which ship

is nearest to the one in distress, to avoid interference as much as possible, and to send help or proceed to give it, whichever can be done the quickest.

The operator must not leave his position at the receiving set while the distress call is being handled. He communicates the fact that an S O S has been heard to the captain through a speaking tube or telephone which is always installed between the radio room and the bridge.

Except in connection with distress calls, the operator is required to operate on the lowest power which will efficiently handle his communications. In case of distress calls these restrictions are all set aside. When trouble arises, the captain of the vessel orders the radio operator to call for help.

In transmitting the distress call the operator arranges his transmitter with the closest possible coupling and highest possible power obtainable on the specified wave length, so as to intentionally cause maximum interference. He then sends . . . – – – . . . several times, followed by his own call letters three times, his ship's position in latitude and longitude if this is known, the nature of the trouble, and information as to whether or not it is a matter of life or death that assistance come *immediately*. Sometimes when it is known that a certain vessel is within range, the S O S may be sent to this ship, in which case the vessel called must reply, and other vessels hearing the message must stop sending and listen. Sometimes in mild cases only a C Q is sent instead of the S O S. Ships of the same company help each other, where possible, in which case there is no charge. Where ships of other companies are given assistance in reply to an S O S, the owners of the assisted ship pay the owners of the assisting ship for the service. One-half of this money is divided among the officers and crew of the assisting ship.

The auxiliary source of power, according to U. S. law, must always be in shape for transmitting distress call communication for a distance of 100 miles, daytime, for a period of at least four hours (international law, 80 miles for 6 hours).

All SOS work is done on 600 meters, and government shore stations keep an operator continuously on watch listening for distress calls on this wave length.

The primary reason for installation of radio apparatus aboard ships is for communication in cases of distress. The number of lives and the ships and valuable cargoes saved since this installation could not be reckoned. A large proportion of these lives and cargoes would probably have been lost. Occasionally a ship equipped with radio apparatus is lost, on account of some sudden and complete demolishing of the vessel; but such cases are very rare. In any ordinary case of distress at sea, there is ample time for communication with other vessels, and for transfer of passengers to other ships. Many of the ships which have been obliged to call for help have only required to be towed. In case of accident to the ship, the radio operator is absolutely under the command of the ship's captain to send exactly such messages at exactly such times as he may direct. In case of disability of the captain to perform his duties the first mate takes his place, and it is the radio operator's duty to take directions from whoever may take temporary command, exactly as if he were the captain. In some very rare and extreme case, when the officers were all unable to handle the work, it might be necessary for the radio operator to take matters into his own hands and do his best to save the ship. Under such circumstances he could not be blamed for going against the rules. His explanation of conditions should not only prevent him from having any trouble, but should bring him the laurels due to a hero. He should be *quite certain* that circumstances justify him, though, before usurping the power which rightfully belongs to others above him.

527. When messages destined for shore are to be transmitted, they are usually sent to the *nearest shore station,* although if there is any reason for the sender desiring otherwise, it may be sent by some other route, provided it does not interfere with the work of other stations. To ascertain the nearest shore station, the operator should *consult the chart.* If the ship is not out of its course, there should be no difficulty in locating the nearest shore station in this way. If necessary, he may send out a "C Q" call, this being a general inquiry for anyone within hearing to answer, but this causes unnecessary interference at the shore station, which might be copying distant signals not audible on the ship. *A "C Q" should not be resorted to unless it is not possible to locate the station otherwise.*

528. When *within five nautical miles of a Government shore station* the operator must not use over one-half kilowatt of power. When within *fifteen miles,* not over one kilowatt of power. In certain cases where communication

with shore stations cannot be accomplished without interference, the Secretary of Commerce may designate the specified time at which certain stations will be permitted to carry on their communication, allowing them to work at different times. When an operator desires to test his apparatus, he is required to call up the nearest radio inspector or Government station, state nature of testing and time required, inquiring if this will cause interference. Or, if out of range of Government shore stations, he should ascertain that testing will not interfere with the work of any ships within his range.

Tactful radio operators, when *in regions where traffic is likely to be congested,* start to call rather gingerly. Many of them make a practice of sending . . . several times, and then listening in to learn if anyone is calling . — . . . , which means *wait.*

529. Communication must be carried on between ships of various companies and systems; and the *law regarding intercommunication* is that *an operator must never refuse to receive or relay a message at the request of another ship station regardless of the system used on the other vessel.*

An operator should make sure that he is familiar with the rates of charging in each particular case, as these vary with different companies and are sometimes changed. The charges for radiograms are based on what is called the *cable count,* being the same system of charging used for cablegrams. This divides the messages into plain language, word code, and cipher.

A *plain language* message consists of an intelligible message in any of the languages using the Roman letters: English, Latin, Italian, French, German, Dutch, Spanish and Portugese. Fifteen letters are counted as a word.

A *word code* message consists of pronounceable words, English, or any one of the above-named languages, but used so that they do not form an intelligible meaning except to a person having the key. Ten letters count as one word in this kind of a message.

A *cipher* message consists of figures or letters having a secret meaning. Five letters or five figures count as one word in a cipher message, but if mixed, for instance B3Y, each character counts for one word.

Fifteen letters or ten letters counting as one word does not mean that two or more words, composed of the allowed number of letters, would be considered as one word. For instance, phosphorescence, in a plain language message would be counted as one word; circumvallations as two words, and "do not buy cartoon" counts as four words.

Charges must be made for the following, and the total charge arrived at by adding the separate charges: Ship's transmitting charge; receiving station charge; relay, if any; land wire charge, if any; war tax, if any. In average cases the transmitting charge is eight cents per word for a passenger vessel and four cents per word for a freighter. A passenger ship may charge twelve or sixteen cents per word. The shore stations generally charge about six cents per word for receiving the message, sometimes ten cents. The address of the person to whom the message is sent, the body of the message and the signature are all charged for, and the number of words entered at the top of the radiogram under the heading of "check." This is transmitted. Sometimes in the address two words, such as New York, if run together (Newyork) are allowed to go as one word. At the top of the radiogram form are also placed the date, the filing number, the name of the origin of the message and the identification letters of the transmitting operator. These are transmitted except the operator's "sine," and his memorandum, as indicated in the following sample transmitted message:

Sample Transmitted Commercial Message

RADIOGRAM

..............................Company

Station S. S. Esparanza. Date Filed September 22nd, 1921

(Not Transmitted)

Prefix	Origin	Sent	Check	Special	Date	Time	To	Routed	Time	Sent by
Radic	S. S. Esparanza	No. 1	20	Prefix	Sept. 22	Filed 9 A. M.	NBZ	Via	Sent 9.15 AM	JM.

Charles Clarke,
1302 James St.
Baltimore Md

Will arrive New York 23rd will investigate conditions mentioned your wire

HUGH SMITH

Charges Collected	Dollars	Cents
Receiving Station	1	20
This Ship	1	60
Cable	....	....
Land Line	....	....
Total Charges	2	80
Total Collected	2	80

SAMPLE ABSTRACT

DIVISION Eastern

OWNERS United States Lines

RADIO CORPORATION OF AMERICA

Abstract of Messages ACCEPTED on S. S. AMERICA From January 1, 1922 To January 31, 1922.

CALL LETTERS KDOW

Sheet No.

Certified Correct
J. A. SMITH
OPERATOR IN CHARGE
A. B. BROWN
ASSISTANT OPERATOR

(1) Accept-ed Date	(2) Name of Coast Station Routed Via	(3) ADDRESSEE	DESTINATION	(4) Prefix	(5) No. of Words	(6) Sent to	(7) Cash Received	(8) Due from Miscellaneous (Note to be made in Column 20 from whom due)	(9) Due from Steamship Company	(10) This Station's Proportion (PAID TRAFFIC)	(11) Due to Radio Corpn. Ship Stations (PAID TRAFFIC)	(12) Due to Radio Corpn. Shore Stations	(13) Due to U. S. Naval Comm. Service	(14) DUE TO Tropical Radio	(15) DUE TO French Govt.	(16) DUE TO United Am'n. Lines	(17) DUE TO British Admiralty	(18) DUE TO M. I. M. C. Co.	(19) DUE TO War Tax	(20) REMARKS
1	Galveston	Hansen	New Orleans	P	17	NKB	$3.40			$1.36			$2.04							
2	New York	Clark	New York	P	10	WNY	2.20			.80		$1.30							$0.10	
3	Cape May	Cole	New York	P	10	WCY		2.10		.80		1.30								Due from "RP" Voucher
4	Ouessant	La Crosse	Brest	D	15	FFU	3.00			1.20					$1.80					Urgent-Rate obtained by "QSJ"
5	New York	Smith	New York	RP	10	WNY	4.20			.80		3.40								RP $2.10
6		Jones	SS Zulia	RP	10	KDZ	3.20			.80	$2.40									RP $1.60
7		Brown	SS Megantic	X	12	KLA	2.88			.96				$0.96				$0.96		Relayed by SS Pastores
8	New London	Dunn	New York	X	6	KDB	1.26			.48		.78								Relayed by SS Caracas
9	Cape May	Lee	Brooklyn	TC	10	WCY	3.15			1.20		1.95								
10	" "	Hill	Philadelphia	POST	20	WCY	3.65			1.60		2.05								Postage five cents
11	New York	Smith	New Orleans	TM3	13/24	WNY	4.02			1.04		2.98								3 street addresses in New Orleans
12	Cape May	Smith-Brown	Tampa, Fla.	TM2	19/26	WCY	5.24			1.52		3.72								
13		Duffy	London	OL	30	KJI	1.80			.84	.96									Ocean Letter Registered
14	Key West	Hydrographic	New Orleans	Govt Hydro	10	NAM														
15	New York	Bliss Dallett	New York	MSG	10	WNY			$1.30			1.30								
16		Captain	SS Caracas	MSG	10	KDB														
17		"	SS Ohioan	MSG	10	WKQ			.80							$0.80				
18	Norfolk	Observer	Washington	Govt WB	8	NAM		.32		.32										U. S. Weather Bureau
19	Chatham	Payne	New York	PDH	10	WCC	.30					.30								RCA Frank No. 75
20	Cape May	Long	Philadelphia	PDH	10	WCY	1.10			.80		.30								RCA Frank No. 90
21	Norfolk	Observer	Washington	Govt WB	8	NAM														
22	Cape May	Idolwolf	New York	Govt SB	15	NSD	.15						.15							
23	New York	"	New York	Govt SB	15	WNY	1.65					1.65								
24		Captain	SS Lake Fear	Govt SB	10	KIVM														
25	Galveston	Idolwolf	New York	MSG	10	NKB	1.50						1.50							
26				QTE			1.20										$1.20			Entered on other side
27				QTE					1.20								1.20			Entered on other side
					308		$43.90	$2.42	$3.30	$14.52	$3.36	$21.03	$3.69	$0.96	$1.80	$0.80	$2.40	$0.96	$0.10	

(8)	(15)
	$14.52
	3.36
	21.03
	3.69
	.96
	1.80
	.80
$43.90	2.40
2.42	.96
3.30	.10
$49.62	$49.62

SAMPLE ABSTRACT SHEET ISSUED BY THE RADIO CORPORATION OF AMERICA TO ITS OPERATORS ON BOARD SEA GOING VESSELS.

(Courtesy of Radio Corporation of America)

Note—The Radio Corporation of America has recently issued separate abstract sheets for messages sent and received between RCA stations and others for work between RCA and stations of other companies. This simplifies the handling of the balance sheets.

ALL MESSAGES ACCEPTED FOR RE-TRANSMISSION ARE ABSTRACTED ON THIS SIDE

RADIO CORPORATION OF AMERICA

(Back of Abstract Sheet)

(Courtesy Radio Corporation of America)

Abstract of Messages RECEIVED on S. S. AMERICA From January 1, 1922 To January 31, 1922.

(1) Received Date	(2) Re-ceived From (Call Letters)	(3) OFFICE OF ORIGIN	(4) Name of Coast Station Routed Via	(5) ADDRESSEE	DESTINATION	(6) Prefix	(7) No. of Words	(8) Deliv-ered or Sent To	(9) Due from Radio Corpn. Ship Stations	(10) Due from Radio Corpn. Shore Stations	(11) Due from Naval Communi-cation Service	(12) Due From Tropical Radio	(13) Due From M. I. M. C. Co.	(14) Due From	(15) Due From	(16) Due From	(17) This Station's Proportion (PAID TRAFFIC)	(18) Due to Steamship Company	(19) Due to Miscel-laneous (Note to be made in column 20 to whom due)	(20) REMARKS
1	WCC	Portland	Chatham	Carney	SS America	P	15	Pub		$1.20							$1.20			$ 0.80
2	WBF	Boston, Mass.	Boston	Hill	" "	P	12	Pub				$0.96					.96			5.70
3	NAM	Norfolk	Norfolk	Clark	" "	P	7	Pub			$0.56						.56			$ 9.48 2.24
4	KTO	SS John D. Rockfeller		Smith	" "	P	10	Pub	$0.80								.80			.80 2.80
5	KLG	SS Santa Marta		Jones	New York	X	10	WNY				.80					.80			2.22 .96
6	KDB	SS Caracas		Smith	Philadelphia	X	11	WCY												
7	KDT	Atlanta	Savannah	Brown	SS America	X	11	Pub			.88						.88			$12.50 $12.50
8	WCY	New York	Cape May	Doyle	" "	RP	10	Pub		2.90							.80		$2.10	RP $2.10
9	MSU	Aquitania		Baxter	Los Angeles	OL	30	Reg					$0.96				.84		.12	Registration
10	KTL	SS Rayo		Captain	SS America	MSG	10	Capt												
11	KMI	SS Tivives		"	" "	MSG	13	Capt				1.04					1.04			
12	WNY	New York	New York	"	" "	MSG	20	Capt												
13	WNY	Philadelphia	New York	"	" "	MSG	10	Capt		.80								$0.80		
14	WCY	New York	Cape May	Meyer	" "	PDH	20	Pub												RCA Frank No. 10
15	WNY	Chicago	New York	Williams	" "	PDH	10	Pub		.80							.80			RCA Frank No. 12
16	KZUU	SS Lake Louise		Captain	" "	Govt SB	12	Capt												
17	NAH	New York	New York	"	" "	Govt SB	10	Capt			.80						.80			
26	GLD	Lands End	Lands End	SS	America	QTE		Capt												Entered on other side
							221		$0.80	$5.70	$2.24	$2.80	$0.96				$9.48	$0.80	$2.22	

EXPLANATION OF THE SAMPLE ABSTRACT SHEET ISSUED TO OPERATORS BY THE RADIO CORPORATION OF AMERICA

"The name "SS. America" as used on this abstract is for illustration only.

The above entries and those on the reverse side illustrate the proper method of abstracting various classes of radiograms. the number given below in respect to each example corresponds with the date of the entry illustrating same.

ACCEPTED MESSAGES

Examples 1 to 14 inclusive apply to all ships operated and controlled by the Radio Corporation.

Examples 15 to 19 inclusive and 27 apply to rental and service contract ships only.

Examples 20 to 26 inclusive apply to Shipping Board ships only.

1. Example of abstracting a paid message sent through a United States Naval station.
2. Example of abstracting a paid message filed within the U. S. three mile limit and sent through an RCA coast station. Note method of entering war tax.
3. Example of abstracting a reply to an "RP" message, or any other message for which an "RP" voucher was accepted in payment, sent through an RCA coast station.
4. Example of abstracting an "Urgent" message, sent through a foreign coast station admitting such messages, and on which the rate was obtained from the coast station by "QSJ." All rates obtained by "QSJ" should be so noted.
5. Example of abstracting an "RP" message sent through an RCA coast station.
6. Example of abstracting an "RP" message sent to another RCA ship.
7. Example of abstracting a paid message relayed by a ship charging for such service.
8. Example of abstracting a paid message sent through an RCA coast station, and relayed by another RCA ship or any other ship making no charge to the Radio Corporation for such service.
9. Example of abstracting a "TC" message sent through an RCA coast station, on which there is an additional charge of one-half the regular tolls for repeating back.
10. Example of abstracting a "POST" message sent through an RCA coast station to be forwarded by ordinary mail.
11. Example of abstracting a "TMx" message sent through an RCA coast station to one person at three street addresses in the same city.
12. Example of abstracting a "TMx" message sent through an RCA coast station to two persons in the same city.
13. Example of abstracting an Ocean Letter.
14. Example of abstracting a "Hydrographic" message.
15. Example of abstracting an "MSG" sent through an RCA coast station.
16. Example of abstracting an "MSG" sent to a ship controlled by the Radio Corporation or an associated company.
17. Example of abstracting an "MSG" sent to a ship *not* controlled by the Radio Corporation or an associated company.
18. Example of abstracting an "Observer" message originating on a rental or service contract ship. Note special rate of ship tax of 4c. per word. No forwarding charges are abstracted on this class of traffic.
19. Example of abstracting a "PDH" sent by the holder of an RCA frank originating on a rental or service contract ship and sent though an RCA coast station.
20. Example of abstracting a "PDH" sent by the holder of an RCA frank originating on a Shipping Board ship and sent through an RCA coast station.
21. Example of abstracting an "Observer" message originating on a shipping Board vessel.
22. Example of abstracting a "Govt. SB" message sent through a U. S. Naval coast station.
23. Example of abstracting a "Govt. SB" message sent through an RCA coast station.
24. Example of abstracting a "Govt. SB" message originating on a Shipping Board vessel and sent to any other Shipping Board vessel, regardless of whether controlled by the Radio Corporation.
25. Example of abstracting an "MSG" originating on a Shipping Board vessel under bare boat charter and therefore not entitled to "Govt. SB" privileges.
26. Example of abstracting a "QTE" received by a Shipping Board ship from a foreign station charging for such service.
27. Example of abstracting a "QTE" received by a rental or service contract ship from a foreign station charging for such service.

RECEIVED MESSAGES

Examples 1 to 9 inclusive and 26 apply to all ships operated and controlled by the Radio Corporation.

Examples 10 to 14 inclusive apply to rental and service contract ships only.

Examples 15 to 17 inclusive apply to Shipping Board ships only.

1. Example of abstracting a paid message received from an RCA coast station.
2. Example of abstracting a paid message received from a Tropical Radio coast station.
3. Example of abstracting a paid message received from a U. S. Naval coast station.
4. Example of abstracting a paid message received from an RCA ship.
5. Example of abstracting a message received for relay from a ship controlled by a company having no reciprocal relay arrangements with the Radio Corporation.
6. Example of abstracting a message received for relay from an RCA ship or any other ship controlled by a company having a reciprocal relay arrangement with the Radio Corporation.
7. Example of abstracting a received message relayed by a ship controlled by a company having *no* reciprocal relay arrangement with the Radio Corporation.
8. Example of abstracting an "RP" message received from an RCA coast station.
9. Example of abstracting an "OL" received from a ship controlled by The Marconi International Marine Communication Co., Ltd.
10. Example of abstracting an "MSG" received from another ship controlled by the Radio Corporation.
11. Example of abstracting an "MSG" received from a ship *not* controlled by the Radio Corporation.
12. Example of abstracting an "MSG" originating at New York or San Francisco, where such messages are filed at Radio Corporation offices.
13. Example of abstracting an "MSG" originating at some point other than New York or San Francisco.
14. Example of abstracting a "PDH" received by a rental or service contract ship.
15. Example of abstracting a "PDH" received by a Shipping Board ship.
16. Example of abstracting a "Govt. SB" received on a Shipping Board ship from any other Shipping Board Ship, regardless of whether controlled by the Radio Corporation.
17. Example of abstracting a "Govt. SB" received from a U. S. Naval station.
26. Example of abstracting a "QTE" received from a foreign station charging for such service, the charges being entered on the accepted side."

530. A received message is headed as follows: Received on board SS ......, Prefix ......, Office of Origin......, Number ......, Check ......, Special prefix ......, Date ......, Time received ......, Received by ....

The following is the usual order of procedure in transmitting a commercial message:

The station to which the message is to be sent is first called by sending the attention signal – . – . – followed by the call letters of the station being called repeated three times de (meaning from) the call letters of the transmitting station repeated three times. The operator in the transmitting station then listens for a response. If the operator in the called station has heard the call, he will answer by making the signal – . – . – followed by the letters of the calling station de his own call letters and the signal – . – meaning "go ahead." After communication has been established between the two stations, the calling station sends the attention signal again, repeating the called station's letters three times de his call letters three times, and proceeds with the following form:

Prefix, Radio,

Origin, Name of vessel,

Number, being number in succession of messages to this station.

Check, number of words in message, transmitted in figures.

Special prefix, if any.

Date. (Spelled out.)

Hour filed. (In figures.)

Break – . . . –

Address.

Break – . . . –

Text of message.

Break – . . . –

Signature.

End of message . – . – .

Call letters of transmitting station.

Go ahead – . – (meaning reply, I am ready to receive).

If several messages are sent, the call letters of the transmitting station are usually not transmitted until the end of the group, the operator waiting for the receiver's . – . after his . – . – . and then proceeding with the next message. When the operator has finished all work he sends the signal . . . – . –

The *accepted number*, being the calling ship's serial number of messages sent, beginning at midnight every twenty-four hours, is sometimes written on the message blank but not transmitted.

Operators often send unofficial signals between themselves, which facilitate their work, such as C?, meaning is everything clear? Or . – . . . for wait. They sometimes send . – . indicating that a message has just been logged, QTB? which is a request that the first letter of each word of the message be sent back in order to check on the check, and QRLL which has come into quite general use as an inquiry to learn if testing will cause interference.

531. One of the important duties of the operator is to keep a regular account of all money handled and hand in an *abstract sheet* on the first of the month, or at any other time designated, to the ship owner or radio company employing him. He is also required to keep a *log*, which is, in reality, a diary. In keeping a log operators are expected to make entries of all calls, and note under remarks the nature of the communication carried on between stations. No messages, sent or received, are to be recorded in the log. Mention is merely made of them as having been handled. The position reports are entered in the log, whether transmitted or not; and the log is handed in at the end of the voyage with the abstract sheet. It should be typewritten if possible. A *station report* is also handed in, reporting condition of apparatus, repairs or spare parts needed, etc.

532. Ship's business messages are defined as follows by the Government: "Messages having relation to the navigation or operation of the vessel passing between the master or other accredited officials on board, and the officials of the U. S. Shipping Board or accredited agents of the person, firm, or corporation assigned as managers or operators of the vessel." These are designated as SB messages, or, if Government work, as Govt. SB. Such messages are sent to naval stations if possible, in which case there is no charge for them. If they are sent to commercial stations, or over land lines, they are entitled to special Government rates.

Besides the SB, there are forms designated as follows, various companies having additional special prefixes:

RP—A message on which a reply is prepaid for a given number of words.

TC—A repeat back message, which is repeated by the receiving station for verification. (Additional charge of one-fourth regular toll.)

Post—A message to be mailed for the sender by the shore station.

PR—A message which is sent from the receiving station by registered mail.

OL—Ocean letter, a message sent from a vessel to another vessel sailing toward a certain port, said message to be mailed by the latter vessel upon arrival in port. Such messages are charged for at usual rates, plus five cents for postage. They cannot be relayed.

Express—Messages which are delivered by special messenger, sometimes beyond the limits of a telegraph office.

SVC—Service messages relating to the handling or routing of messages, tariff, etc. They must be entered in the abstract sheet, but are not charged for.

MSG—Unofficial communication between officers of ships.

Radio St—A paid service message, sent at the request of the sender of a regular message.

DPR—Daily press rate.

TMX—A multiple radiogram, addressed to two or more persons at different addresses. This is sent as a single radio message, but if forwarded over a land line to the different addresses is charged for as separate messages.

WB—Weather Bureau message, handled through the naval stations and not charged for.

Relay—Being a message which is to be relayed to another radio station farther on. (R. C. A. uses X for this.) *

TR—Position report. (Being done away with to reduce interference.)

DH—Dead head, not charged for. (The radio operator is usually allowed about 30 words per month, free of ship or coast tax, if sent between stations of the same company.) If a land line is included, this must be paid.

European vessels use "D" as a prefix meaning *urgent*. Such messages are not customarily accepted by American ships.

533. A *radiogram may be repeated three times,* at the request of the receiving station. If its reception is still in doubt it should be cancelled.

When a radiogram contains more than forty words, the transmitting station should interrupt the transmission after each series of about twenty words, sending . . – – . . , not resuming until he has received a repetition of the last word and – . – from the receiving station.

In *calling a station,* the called station's call letters *may be repeated three times, at an interval of two minutes.* If they do not answer, the call should not be sent out again until 15 minutes have elapsed.

Messages to be *relayed* by a ship of another company are charged for at the rate of receiving and retransmitting by the second ship, except in certain cases where ship owners have agreed to reciprocate in relaying a specified number of messages per month without charge. Between vessels of the same company relaying is not charged for.

When an *acknowledgment* is desired, the transmitting station adds the word "acknowledge" at the end of the message after the signature but before . – . – ., the receiving operator acknowledging such a message by repeating the call letters of the transmitting station de his own call letters.

When the *land-line forwarding rate* is not known to a ship's operator, he can call the shore station, requesting this information. The latter is required to give the rate to the operator on the vessel. However, the ship's operator should not call for this purpose unless necessary. The signal QSJ may be used for this purpose.

Some passenger liners have *branch banks,* branches of banks on shore. Money can be sent through these branch banks to any other branch of the same banking company. It is sent in secret code and can be forwarded by land line as usual with land-line money orders. Where no branch bank is on board, no provisions have yet been made for accommodating a passenger desiring to have money sent in either direction, as a request for this is very rare.

A supplement to the Instructions to Operators is supplied, containing the *rate of exchange* of moneys of different countries. As some of the money is of fluctuating value, it is necessary to always use the latest supplement in determining the charges for a radiogram in foreign money.

Time, weather reports and *press* are sent out by the Government shore stations daily, in some places twice daily, at previously arranged times. It is the duty of the operator to receive the time and weather reports. The amount of press which he copies is, in most cases, a matter of choice, but as it is like receiving a daily newspaper when all other sources of news are beyond reach, no operator would care to miss receiving this. It is his *privilege* to keep his captain supplied with the daily news.

534. The international list of abbreviations, as given out by the Department of Commerce, is herewith reproduced. The convenience of these abbreviations is obvious. Another abbreviation which is used occasionally, and concerning which there has been considerable misunderstanding among students, is P R B ?, meaning, "Do you wish to communicate by means of the International Signal Code?" This does not refer to the Continental code, nor to the international abbreviations. It signifies the *International Flag Signaling Code,* which was originally confined solely to communication by means of a flag code between vessels within sight of each other; but which, since radio communication between vessels has become indispensable, has been adapted to radio. For instance, in the *International Code of Signals, No. 87,* published by the U. S. Hydrographic Office, OKN, means "You are within range of the guns." If the vessels are within sight of each other, this message may be sent by hoisting three flags, indicating letters of the alphabet, arranged vertically in order on a signal halyard; a flag divided biasly into a red and a yellow half for O; a flag divided vertically into a yellow and a blue half for K, and a flag composed of blue and white checks for N. *Or, if the vessels are not within sight, OKN, sent by radio will mean exactly the same thing.* By having the sentence translated into different languages, in the hands of all operators of all nationalities, an English-speaking operator can send the same message to any other operator who does not speak English, or vice versa. As there are thousands of such code signal sentences, extended communication can be carried on by this method.

The QRL abbreviation is also sometimes misunderstood as meaning to send twenty words per minute, instead of its true meaning, which is to send . . . —. twenty times, so that the receiving operator can adjust his receiving set to resonance with the transmitter.

ABBREVIATIONS USED IN RADIO COMMUNICIATION

Abbreviation	Question	Answer or Notice
QRA...	What ship or coast station is that?........	This is....
QRB...	What is your distance?..................	My distance is....
QRC...	What is your true bearing?..............	My true bearing is....degrees
QRD...	Where are you bound for?..............	I am bound for....
QRF...	Where are you bound from?.............	I am bound from....
QRG...	What line do you belong to?............	I belong to the....Line
QRH...	What is your wave length in meters?......	My wave length is....meters
QRHH.	What tune shall I adjust for?............	Adjust to receive on tune....
QRJ...	How many words have you to send?......	I have....words to send
QRK...	How do you receive me?.................	I am receiving well
QRL...	Are you receiving badly? Shall I send 20?... . . . — . for adjustment?	I am receiving badly. Please send 20........... . . . — . for adjustment.
QRLL.	Request permission to test....minutes....	Permission to test granted.
QRM..	Are you being interfered with?...........	I am being interfered with.
QRN...	Are the atmospherics strong?............	Atmospherics are very strong.
QRO...	Shall I increase power?.................	Increase power.
QRP...	Shall I decrease power?..................	Decrease power.
QRQ...	Shall I send faster?......................	Send faster.
QRS...	Shall I send slower?......................	Send slower.
QRT ..	Shall I stop sending?....................	Stop sending.
QRU...	Use as question discontinued............	....
QRU...	....	I have nothing for you.
QRV...	Are you ready?..........................	I am ready. All right now.
QRW..	Are you busy?...........................	I am busy (or: I am busy with....) Please do not interfere.
QRX...	Shall I stand by?.......................	Stand by. I will call you when required
QRY...	When will be my turn?...................	Your turn will be No.....
QRZ...	Are my signals weak?..................	Your signals are weak.
QSA...	Are my signals strong?..................	Your signals are strong.
QSB...	—Is my tone bad?.......................	The tone is bad.
	—Is my spark bad?......................	The spark is bad.
QSC...	Is my spacing bad?.....................	Your spacing is bad.
QSD...	What is your time?.....................	My time is.....
QSF...	Is transmission to be in alternate order or in series?	Transmission will be in alternate order.
QSG...	....	Transmission will be in series of 5 messages.
QSH...	....	Transmission will be in series of 10 messages
QSJ....	What rate shall I collect for?............	Collect........for...........................
QSK...	Is the last radiogram canceled?...........	The last radiogram is canceled.
QSL...	Did you get my receipt?	Please acknowledge.
QSM...	What is your true course?............ ...	My true course is....degrees.
QSN ..	Are you in communication with land?.....	I am not in communication with land.
QSO...	Are you in communication with any ship or station (or: with....)?	I am in communication with.... (through....).
QSP...	Shall I inform....that you are calling him?	Inform....that I am calling him.
QSQ...	Is....calling me?.......................	You are being called by....
QSR...	Will you forward the radiogram?.........	I will forward the radiogram.
QSS...	Are my signals fading?..................	Your signals are fading.
QST...	Have you received the general call?.......	General call to all stations.
QSU...	Please call me when you have finished (or at....o'clock).	Will call when I have finished.
QSV[1]..	Is public correspondence being handled?...	Public correspondence is being handled. Please do not interfere.
QSW...	Shall I increase my spark frequency?......	Increase your spark frequency.
QSX...	Shall I decrease my spark frequency?.....	Decrease your spark frequency.
QSY ...	Shall I send on a wave length of....meters?	Let us change to the wave length of....meters.
QSZ...	....	Send each word twice. I have difficulty in receiving you.
QTA...	....	Repeat the last radiogram.
QTC...	Have you anything to transmit?..........	I have something to transmit.
QTE...	What is my true bearing?................	Your true bearing is....degrees from....
QTF...	What is my position?...................	Your position is....latitude....longitude.

[1] Public correspondence is any radio work, official or private, handled on commercial wave lengths.
When an abbreviation is followed by a mark of interrogation, it refers to the question indicated for that abbreviation.

Rates for charging for messages vary from time to time, the charge per word being changed when it seems advisable, so that any rate sheet may not be correct unless of the most recent date. A rate sheet, U. S. Naval Communication Service, published at the Government Printing Office, Washington, D. C., is always on the desk of a marine radio operator. An abbreviated extract from such a sheet is shown here, giving a general idea of the arrangement of the sheet. (The complete rate sheet is too voluminous to reproduce.)

LANDLINE TARIFFS TO NORTH AMERICAN POINTS

To	Chatham-Marion—WCC Chatham—WIM New York—WNY Tuckerton, N. J.—WSC	San Francisco, Calif.—KPH	Los Angeles, Calif.—KSE
Alabama	$0.07	$0.11	$0.11
Alaska	.16	.12	.12
Alberta	.11	.11	.11
Arizona	.11	.07	.06
Arkansas	.07	.11	.11
British Columbia	.11	.07	.07
California	.11	......	......
Alameda, Berkeley, Oakland, San Francisco	....	.03	.04
Los Angeles	....	.04	.03
Other offices	....	.04	.04
Colorado	.11	.09	.09
Connecticut	.03	.09	.09
Delaware	.04	.11	.11
District of Columbia	.04	.11	.11
Florida: Key West	.11	.15	.15
Other offices	.07	.11	.11
Georgia	.07	.11	.11
Idaho	.11	.07	.09
Illinois	.06	.09	.09
Indiana	.06	.11	.11
Iowa	.07	.09	.09
Kansas	.07	.09	.09
Kentucky	.06	.11	.11
Labrador	.13	.21	.22
Louisiana	.07	.11	.11
Maine	.05	.11	.11
Manitoba	.09	.11	.11
Maryland	.04	.11	.11
Massachusetts	.04	.11	.11
Mexico:			
Mexico City, Vera Cruz, Merida, Tampico, Tuxpam, Salina Cruz, Mazatlan and other offices in Central and Southern Mexico	.18	.18	.18
Monterrey, Jiminez, La Paz, Santa Rosalia, Nogales, Chihuahua, Guaymas, and other offices in Lower California and Northern Border States of Mexico	.07	.07	.07
Michigan	.06	.11	.11
Minnesota	.07	.09	.11
Mississippi	.07	.11	.11
Missouri	.07	.09	.09
Montana	.09	.09	.09
Nebraska	.07	.09	.09

To	Chatham-Marion—WCC Chatham—WIM New York—WNY Cape May—WCY	San Francisco, Calif.—KPH	Los Angeles, Calif.—KSE
Nevada	$0.11	$0.06	$0.06
New Brunswick	.06	.11	.11
Newfoundland	.12	.17	.18
New Hampshire	.04	.11	.11
New Jersey	.03	.11	.11
New Mexico	.09	.09	.07
New York	....	.11	.11
New York City	.03	......	......
Other offices	.04	......	......
North Carolina	.06	.11	.11
North Dakota	.09	.09	.09
Nova Scotia	.06	.11	.11
Ohio	.05	.11	.11
Oklahoma	.09	.09	.09
Ontario	.06	.11	.11
Oregon	.11	.06	.07
Pennsylvania	....	.11	.11
Philadelphia	.03	......	......
Other offices	.04	......	......
Prince Edward Island	.08	.13	.15
Quebec	.06	.11	.11
Rhode Island	.04	.11	.11
Saskatchewan	.11	.11	.11
South Carolina	.07	.11	.11
South Dakota	.09	.09	.09
Tennessee	.06	.11	.11
Texas	.09	.09	.09
Utah	.09	.07	.07
Vermont	.04	.11	.11
Virginia	.05	.11	.11
Washington	.11	.07	.07
West Virginia	.05	.11	.11
Wisconsin	.07	.09	.11
Wyoming	.09	.09	.09
Yukon:			
Carcross, or Caribou Crossing, White Horse	....	.27	.27
Cowley	....	.33	.33
Big Salmon, Boundary North, Carmacks, Coffee Creek, Conrad, Dawson, Fort Selkirk, Forty Mile, Hootalinqua, Livingston Creek, Laverdiere, Lower Labarge, Mason's Landing, Tagish, Yukon Crossing	....	.37	.37
Oglivie. Stewart River	....	.47	.47

INTERNATIONAL RADIO TARIFFS "VIA RCA"

Direct Service from New York to

England, Norway — France, Poland — Germany, Italy

Connections to all parts of the world

Add coastal station and ship tolls to tariff shown below to obtain full through tariff per word.

Rates subject to change without notice.

To	Via WCC WIM WNY WSC	Via KPH KSE	To	Via WCC WIM WNY WSC	Via KPH KSE
Alsace-Lorraine	$0.22	$0.34	Holland	$.25	$.37
Australia	.66	.58	Hungary	.33	.47
Austria	.30	.44	Ireland	.20	.34
Azores	.25	.37	Italy	.26	.40
Belgium	.23	.37	Japan	.87	.72
Bermuda	.36	.46	Luxemburg	.27	.41
China:			New Zealand	.58	.50
Kwangtung Peninsula, Tsing Tau and South Manchuria (Japanese Offices only)	.87	.72	Norway	.24	.38
Macoa	1.05	.93	Philippine Islands (Manila)	.92	.80
All other offices	1.00	.88	Poland	.25	.39
Dantzig (Free Town)	.27	.41	Portugal	.35	.49
Denmark	.25	.39	Scotland	.20	.34
England	.20	.34	Spain	.33	.47
Finland	.29	.43	Sweden	.26	.40
France	.22	.34	Switzerland	.27	.41
Germany	.25	.39	Wales	.20	.34
Greece	.35	.49	Colon (Canal Zone)	.30	.42
Guam	.77	.65	Balboa (Canal Zone)	.30	.42
Hawaiian Islands:			Havana (Cuba)	.15	.20
Honolulu	.37	.25	Rio de Janeiro (Brazil)	.50	.62
Other Islands	.52	.40	Buenos Aires (Argentine)	.50	.62
			San Juan (Porto Rico)	.40	.45

LOG

Log, S. S. Esparanza — Voyage from Baltimore to Vera Cruz, Mex.

Time	Station Called	Called By	Remarks
9.00 AM	....	KDT	QTC? QRU
9.15 AM	....	KSA	QTC? QRU
9.45 AM	NBZ	....	Sent SVC MSG.
10.00 AM	KSA	NCC	QRA-etc.
10.02 AM	NCC	KSA	QRA SS Espaniola, bound Havana.
10.15 AM	WSE	....	Press? No answer.
10.30 AM	....	KSA	QSD?
10.33 AM	NAH	....	Sent RDO for Norfolk.
11.00 AM	NAH	NAI	
11.15 AM	WHB	WDU	
11.30 AM	WHB	WDU	New York Herald WKG Cleveland.
12.00 M	....	....	Noon Position. Lat. North 40° Long. West 60°

535. Besides being able to transmit and receive the Continental code with the usual transmitting and receiving apparatus, it is necessary for a radio operator employed on seagoing vessels to be able to send and receive the code with a *"blinker."* This usually consists of a small electric lamp attached to a pole above the bridge and connected in the regular lighting system of the ship. A transmitting key is connected in series with the lamp for signaling, this usually being mounted at the base of the pole. (In some cases a flash-light is used.) In sending it is necessary to manipulate the key carefully, and the touch is a little different from that used in sending "spark signals." If sufficient time is not given for the current to heat the filament to incandescence the light signals will not be readable as "dots and dashes." In order to copy this kind of signaling it is necessary to be able to remember the letters as they are sent, and read the sentence without copying it down, as the work is done in the dark. Signaling is usually done at about 10 words per minute or less. The blinker is especially useful in harbor for communication between vessels, or near a lightship which is not equipped with radio apparatus. The distance to which it is practical is between two and three miles. If an operator is requested to send or receive a blinker message for the captain, he is obliged to do it; so it is well for a prospective radio operator to practice with the blinker, as well as with the other apparatus, and become efficient in this kind of communication.

536. The bulletin of the *United States Shipping Board* Emergency Fleet Corporation gives the following instructions regarding the *duties of the radio operator:* "When operators are requested by a coastal station to cease transmitting, they must do so and wait until the coastal station transmits the signal indicating that the air is clear. In all radio communications, use minimum power and work with the nearest station handling commercial traffic; however, all Government SB messages should be given to U. S. Navy radio stations whenever practicable. Radio operators should be brief and always use the 'List of abbreviations to be used in Radio Communication,' as authorized by Art. 22 of the Service Regulations when asking questions. Several instances have come to our attention where an operator has transmitted a radiogram to another vessel for relay to a shore station, without ascertaining through what shore sta-

tion the radiogram is put on a land line. As a consequence, he fails to learn the amount of the land line charge, and cannot, therefore, properly account for this charge on his abstract, nor collect the proper charge from the sender. In all cases, the operator on ship of origin will service the relaying vessel and learn at once the amount of the land line charge and whether or not ship to which transmitted makes relay charge.

Masters and radio operators should thoroughly understand the necessity for acknowledging certain messages. "Acknowledge" means for the master to reply by radiogram whether or not the instructions received are understood. All radiograms received by masters of Shipping Board vessels referring to the operation or diversion of a vessel should be acknowledged by a reply radiogram.

Radio operators must know the communication range between their vessel and the various coastal stations, in order that the master of the vessel may acknowledge receipt of the message at the earliest opportunity.

The attention of all operators is invited to the manner of handling the Govt. SB" messages, *Commercial Traffic Regulations,* U. S. Navy, Chapter V, par. 128. Much adverse criticism is being received regarding the generally slip-shod manner in which Shipping Board operators are handling this class of traffic.

Two *vacuum tubes,* together with standard base, will be issued by Radio Supervisors to radio operators upon application whenever considered advisable. The type of tube issued will be Western Electric VT 1, and operators are cautioned that in no case must filaments be permitted to burn above a very dull red. If this condition is exceeded the filament will be destroyed. Furthermore, operators will find the best results are obtained when the tubes are used as above directed. Renewals can only be furnished when old parts are returned to radio supervisors. Tubes will not be transferred from one vessel to another and the sale of a tube will be sufficient cause for immediate dismissal from the service."

537. A book containing instructions to operators, published by the radio company or ship owners employing the operator, is always supplied to the operator when he takes a position on board ship. The *Commercial Traffic Regulations* of the U. S. Navy ($1.00 at Government Printing Office,

Washington, D. C.), is also often furnished. While the various companies vary slightly in their procedures, there is little difference in their general instructions, abbreviations for messages, etc. The following group of general rules serves as an example of the usual Instructions to Operators:

Immediately after being assigned to a ship the operator should obtain a copy of the *ship's inventory* of radio apparatus from the company's representative, check it against apparatus on board, and sign a receipt. If he cannot obtain this, the operator should make an inventory. Upon being transferred or leaving the service, the operator must obtain a receipt from the incoming operator for the equipment and spare parts. Operators are held accountable for the apparatus in their custody and all shortages are reported to the bonding company for investigation.

All operators are required to furnish bond with the American Surety Company; a fidelity bond of $250.00 on which the premium is $1.00 per year, and a property bond on which the premium is $5.00 per year. Operators are automatically bonded the date they enter service, but formal application should be filled out and premiums paid at the time of entering the service. Failure to do this, or rejection by the bonding company will be sufficient cause for dismissal. The second yearly premium of $6.00 is due and payable at any branch office one year from date of entering the service.

When a ship docks at a port the senior operator must immediately report his arrival to the branch office manager either in person or by telephone, and state whether or not any repairs are required.

On ships where only one operator is employed, the operator must notify the master or chief officer before going ashore. On ships carrying one operator the hours of watch should be so arranged as to include all schedules of stations in vicinity, and such additional periods as the master may direct. On vessels carrying two or more operators, continuous watch shall always be maintained.

The radio room key must never be taken off the ship. When the operator goes ashore the key should be handed to the master or chief officer. This is a Department of Commerce regulation. The key should never be left with the steward.

Operator's license cards must be framed and hung conspicuously on the wall of the radio room.

The ship's call letters must be printed in ink in block letters about one inch in height and posted conspicuously over the operating table. This is required by the Department of Commerce.

The business of a radio office is strictly private and no unauthorized persons should be allowed access to the room.

All messages, logs, etc., are strictly confidential, and *no information shall be given out excepting to duly authorized persons.*

Operators *must not retransmit* or divulge private press messages not addressed to them. This is in accordance with the International Agreement regarding secrecy of messages.

All broadcast press dispatches copied by an operator must be submitted to the master and then, if approved, distributed or posted on the bulletin board.

The radio room and apparatus must be kept clean. All moving parts should be kept well oiled, and exposed parts greased or oiled to prevent corrosion. Telephone diaphragms should be wiped with slightly oiled cloth to prevent rust. *No alterations or additions shall be made to apparatus or wiring. Repairs that are beyond the ability of the operator, or for which proper facilities are lacking on shipboard, must be requested of the nearest company representative upon arrival in port.*

538. The practical radio operator will find it a help in the performance of his duties if he understands the *reckoning of time* and *dates.* Greenwich, a small town outside of London, is the zero of Longitude and the international "time line." Longitude is reckoned East and West from that point; and the *ship's apparent time* is the time, computed from Greenwich, in the Longitude in which the ship is located at the time of reckoning. 15° Longitude is equal to one hour of time, Greenwich being in the center of the first zone. When seven and a half degrees East or West of that point, clocks must be changed. If going East, one hour is added; and if going West one hour is subtracted. After this, going East or West, every fifteen degrees constitutes a *time zone.* These are now uniform throughout the world on land and sea. Greenwich Mean Time, or G.M.T., was the traditional nautical time standard, based on the astronomical day from *noon* to *noon.* This was originated by as

tronomers, on account of the inconvenience which would be caused to them in changing dates of observations in the middle of the night. As the fundamental system of navigation depends almost exclusively on astronomical observations, this was the day which became associated with the sea; and nautical almanacs were for generations based on this arrangement. Unspeakable confusion has resulted in many ways, and the system of having one set of dates for the sea and another for land no longer fits in with modern ideas of efficiency. Hence, the new nautical almanac, beginning January 1, 1925, discards the use of the astronomical day for the sea; and the same day, from 12 *midnight* to 12 *midnight* thereafter obtains on both land and sea. This is known as *Greenwich Civil Time,* or G. C. T. *Paris Time* is a few minutes different from the Greenwich Time. M. E. Z. is sometimes used to designate the Middle European Time Zone, being the zone which is one hour east of Greenwich. The International Date Line passes around the earth at about 180°, but does not follow this line exactly.

539. In order to obtain a *position on a first-class passenger vessel,* it is necessary for a radio operator to have gained some practical experience on some of the smaller ships carrying freight, or freight and a few passengers.* The requirements for the Leviathan's chief radio operator are as follows:

1. Able-bodied man, over 21, of neat appearance and good address.
2. American citizenship.
3. First class, first grade license, or better.
4. Speed and ability in receiving messages on typewriter.
5. Professional ability in handling traffic in general.
6. Receiving radio telegraph ability.
7. Sending ability.
8. Knowledge of tube transmitters and receivers.
9. Experience with tube transmitters.
10. Personality.
11. Executive ability.
12. Knowledge of theory and operation of radiotelephone.
13. Ability to copy from high-speed recording tape, which means copying on a typewriter.

*Among the first things experienced by a seagoing radio operator are likely to be the *fire drill and life-boat drill.* In some cases operators may secure a boatswain's license in order to be permitted to row a life-boat.

Of course, the remuneration for this position is in keeping with its requirements.

To obtain a *radio operator's license,* it is necessary to go to the office of the nearest radio inspector and pass an examination in transmitting and receiving the continental code and a written examination in theory. The grades and classes as now given out by the Department of Commerce are as follows:

"1. The Commercial First Class and the Commercial Second Class radio operator's licenses which replaced the commercial first grade and commercial second grade licenses on July 1, 1921, will be issued to applicants who pass the examination previously given for the first and second grade licenses. Holders of first and second class licenses, irrespective of grade, will be eligible for employment in any station formerly requiring first and second grade licenses.

2. The first license issued to a student from a school will be first or second class, depending upon the examination, and will be third grade as he has not had any practical radio service. After securing a first or second class license of the third grade he must serve six months before he wlil be entitled to a second grade license of the same class, and if he holds a second class license he must pass the code speed at the rate of twenty words.

3. The grading merely indicates the service an operator has had and his code speed. It does not change his status so far as employment is concerned."

(See Appendix for radio operator's licenses.)

540. The United Fruit Company announces the inauguration of a free medical radio service from its hospitals in the various countries of Central America and from its passenger steamships to all ships at sea. So far as the United Fruit Company and its subsidiary companies are concerned, this service is available without charge to ships of all nationalities through the following radio stations operated by the United Fruit Company or the Tropical Radio Telegraph Company:

Free Medical Radio Service for Ships at Sea.

Radio Stations and Their Call Letters

New Orleans, Louisiana....................WNU
Burwood, Louisiana........................WBW
Fort Morgan, Alabama......................WIO
Swan Island, Caribbean Sea..................US
Tela, Honduras..............................UC
Puerto Castilla, Honduras...................UA
Tegucigalpa, Honduras (Open Nov., 1922).....UG
Port Limon, Costa Rica......................UX
Almirante, Panama...........................UB
Santa Marta, Colombia.......................UJ

All passenger steamships of the United Fruit Company.

For ships' call letters, see International Radio Call Letter List.

Radiograms requesting medical advice should be signed by the captain of the ship and should state briefly, but clearly, the symptoms of the person afflicted. Such radiograms should be addressed "Unifruitco" (name of place) and may be sent to any of the United Fruit Company's hospitals listed below:

Santa Marta, Colombia	Tela, Honduras
Port Limon, Costa Rico	Puerto Castilla, Honduras
Almirante, Panama	Puerto Barrios, Guatemala

All United Fruit Company passenger steamships carry doctors and free medical service may be secured by radio from any of them by a radiogram addressed "Ships' Doctor" followed by the name of the steamship.

This free medical service is established primarily for the benefit of ships not carrying doctors; however, should occasion require, ships' doctors may hold consultation by radio with the United Fruit Company ships' doctors and hospital staffs.

The physicians and surgeons comprising the medical staff of the United Fruit Company and its subsidiaries are thoroughly qualified, but in view of the fact that radio medical advice to ships at sea is given free and without an opportunity for a personal examination of the patients by them, no responsibility will be assumed by either the company and its subsidiaries or the physicians or surgeons giving the advice as to its accuracy or for error in the receipt or transmission of any message sent or received in connection therewith.

It is requested that when sending medical advice radiograms, radio operators check them "(number of words) DH Medico."

"DH Medico" radiograms will be given preference over all other radiograms, excepting S O S calls, throughout the radio service of the United Fruit Company and subsidiary companies.

Medical assistance may also be obtained from the naval shore stations. The "Dead Head Medico" form being used for calling.

CHAPTER 44

Safety Precautions and Resuscitation

Underwriters' Regulations — Recommendations for Safety—Warnings — Protection from High-Power Induction—Storage-Battery Dangers—Instructions for Removing a Person from Contact with High-Potential Wire—Artificial Respiration.

541. It is not the purpose of this chapter to instill fear of radio apparatus, but to call attention to the fact of possible danger, of where it may be and of how to avoid trouble due to carelessness or lack of knowledge. Electricity is probably our greatest servant; but like fire and water, which serve mankind so well, those who utilize its power must know how to handle it in order that it may not destroy instead of serve.

Certain safety precautions are necessary in the use of any electrical apparatus, and when high-voltage alternating current is used, as in radio transmitting, the need of care should be especially emphasized. The requirement for a lightning switch has been previously explained. A separate ground, 30 or 40 feet removed from the transmitting and receiving ground should be used. When installing radio apparatus it is wise to investigate the fire underwriters' rules for radio installations in your locality, as they differ somewhat. Or, the National Fire Underwriters of New York will supply the information. The Bureau of Standards' publication, *National Electric Safety Code,* which may be purchased for 40 cents from the Government Printing Office, Washington, D. C., contains information which is the result of extensive Government experiments relative to safety precautions.

In making installations, one should always examine the insulation on all wires to be used for high voltage, and if it is broken or crumbled the wire should be discarded. If there is simply a break or two in otherwise good insulation, these places may be repaired by dipping in warm paraffine and binding with plenty of friction tape. All wires connected to a transmitter should be kept as far apart as possible, and several feet from all power wires, telephone wires, etc., also, they should be placed out of the way of the operator. Porcelain cleats are convenient for insulating supports for wires of low powered sets. Do not stand on grounded metal pipes, radiators, etc., while working around electric wires. If on the earth, insulate the body by wearing rubbers.

Admiral Robison, of the U. S. Navy, says in his *Manual of Radiotelegraphy and Telephony*: "The charge and discharge of a condenser when not sparking is indicated by a rustling sound which signifies danger. This warning applies equally to induction coils and transformers, both terminals of which are dangerous when using alternating current. On account of the small penetrating effect of high-frequency currents, it is believed that high voltages when associated with frequencies of above 100,000 per second are not dangerous to human life, but *low-frequency, high-voltage currents are very dangerous,* and it must be borne in mind that a condenser being charged and discharged at the alternator frequency is very much more dangerous than when it is discharging across the spark gap."

This does not mean, however, to take foolish chances with high-voltage current simply because it is of a frequency above 100,000 cycles.

High-frequency wires of the apparatus or the antenna should not run parallel to supply wires or telephone wires; and the power supply wires should always be run in a metal conduit which is grounded. This protects adjacent power lines or telephone wires from high-frequency induced current, which sometimes causes considerable trouble both in the way of damaging apparatus and injury to persons. Special care should be observed in installing a rotary gap, to see that it is true and properly spaced. Otherwise there may be greater disturbance from high-frequency induced currents than with some other types of transmitting apparatus. The precautions needed in operating the arc transmitter are included in the chapters dealing with the arc. High-powered arc sets are quite dangerous if intelligent precautions are not observed.

Always keep flames away from storage batteries, as the gas arising from them has been known to ignite and cause an explosion, severely burning people. Also in handling sulphuric acid for electrolyte one should be cautious not to get the pure acid on the skin or clothing. It will ruin clothing, shoes and carpets, and may cause a disagreeable burn on the skin. If acid is accidentally spilled on the skin, apply ammonium hydroxide, or bicarbonate of soda immediately.

Avoid dangling neckties, which may get caught in revolving power machinery and draw the wearer into danger.

542. Following are extracts from the Underwriters' Regulations:

UNDERWRITERS' REGULATIONS

March 12, 1923

Note:—These rules do not apply to Radio Equipment installed on shipboard.

In setting up Radio Equipment all Wiring Pertaining thereto must conform to the General Requirements of the National Electrical Code for the class of work installed and the following Additional Specifications:

For Receiving Stations Only

(Sections **a** to **d**, inclusive, do not apply when antenna is installed inside of buildings.)

Antenna:

a. Antenna and counterpoise outside of buildings shall be kept well away from all electric light or power wires of any circuit of more than 600 volts, and from railway, trolley or feeder wires, so as to avoid the possibility of contact between the antenna or counterpoise and such wires under accidental conditions.

Antenna and counterpoise where placed in proximity to electric light or power wires of less than 600 volts, or signal wires, shall be constructed and installed in a strong and durable manner, and shall be located and provided with suitable clearances, so as to prevent accidental contact with such wires by sagging or swinging.

Splices and joints in the antenna span shall be soldered unless made with approved splicing devices.

Light and power circuits, if used for receiving antenna, need not conform to any of the above requirements, but the devices used to connect the light and power conductors to radio receiving sets must be of an approved type.

Lead-In-Conductors:

b. Lead-in conductors shall be of copper, approved copper-clad steel or other metal which will not corrode excessively, and in no case shall they be smaller than No. 14 B. & S. gauge except that bronze or copper-clad steel not less than No. 17 B. & S. gauge may be used.

Lead-in conductor on the outside of buildings shall not come nearer than four (4) inches to electric light and power wires unless separated therefrom by a continuous and firmly fixed non-conductor that will maintain permanent separation. The non-conductor shall be in addition to any insulation on the wire.

Lead-in conductor shall enter building through a non-combustible, non-absorptive insulating bushing slanting upward toward the inside.

Protective Device:

c. Each lead-in conductor shall be provided with an approved protective device (lightning arrester) which will operate at a voltage of five hundred (500) volts or less, properly connected and located either inside the building at some point between the entrance and the set which is convenient to a ground (see section **d**), or outside the building as near as practicable to the point of entrance. **The protector shall not be placed in the immediate vicinity of easily ignitable stuff, or where exposed to inflammable gases or dust or flyings of combustible materials.**

The use of an antenna grounding switch is desirable, but does not obviate the necessity for the approved protective device required under this section. The antenna grounding switch if installed shall, in its closed position, form a shunt around the protective device.

A knife switch not less than 30 amp., 250 volts, is recommended to be located between lead-in conductor and receiving set.

Fuses are not required, but if used shall not be placed in the circuit from the antenna through the protective device to ground.

Protective Grounding Conductor:

d. The protective grounding conductor may be bare and shall be of copper, bronze or approved copper-clad steel. The grounding conductor shall not be smaller than the lead-in conductor, and in no case shall be smaller than No. 14 B. & S. gauge if of copper, nor smaller than No. 17 B. & S. gauge if of bronze or copper-clad steel. The grounding conductor shall be run in as straignt a line as possible from the protective device to a good, permanent ground. **Preference shall be given to water piping.** Other permissible grounds are grounded steel frames of buildings or other grounded metal work in the building, and artificial grounds such as driven pipes, rods, plates, cones, etc. **Gas piping shall not be used for the ground.**

The grounding conductor shall be protected where exposed to mechanical injury. An approved ground clamp shall be used where the grounding conductor is connected to pipes or piping.

Receiving Equipment Grounding Conductor:

e. The grounding conductor may be run either inside or outside of the building. The protective grounding conductor and ground installed as specified in Section **d** may be used as the operating ground. In this case the operating grounding conductor should preferably be connected to the ground terminal of the protective device.

If desired. a separate operating grounding connection and ground may be used, the grounding conductor being bare or with an insulating covering.

Wires Inside Buildings:

f. Wires inside buildings shall be securely fastened in a workmanlike manner and shall not come nearer than two (2) inches to any electric light or power wire not in conduit, unless separated therefrom by some continuous and firmly fixed non-conductor making a permanent separation. This non-conductor shall be in addition to any regular insulating covering on the wire. Porcelain tubing or approved flexible tubing may be used for encasing wires to comply with this rule.

Storage battery leads shall consist of conductors having approved rubber insulation. It is recommended that the circuit from the storage battery be properly protected by fuses located as near as possible to the battery.

The following regulations are recommended by Major Holcombe:

"No part of any radio equipment shall be erected in, or along, or across any public street, avenue, road, highway, alley or other public space, and no wire in connection with use or intended for radio reception shall be, when erected or in course of erection, within twenty feet of any electric light, power, or communication wire.

"No pole, mast, guy or support for any wireless aerial shall be placed in or attached to any soil stack, vent pipe or other plumbing appurtenance. No pole, mast or support exceeding twenty feet in height shall be erected without the approval of the inspector of buildings. When deemed necessary by the inspector of buildings a sketch showing the dimensions and proposed method of securing such pole or mast shall be submitted."

543. As anyone working around high-potential electric machinery is continually exposed to the danger of shock, it is well for all such persons to know what to do for a fellow-worker in case of an accident. Most accidents of this nature can be avoided by observance of ordinary care and precaution, but in spite of the knowledge of danger many people will persist in careless handling of electrical apparatus. Directions for the resuscitation of a person who has suffered electric shock are given below. The quotations are from publications of the American Medical Association and the National Electric Light Association:

"*An accidental electric shock usually does not kill at once, but may only stun the victim and for a while stop his breathing.* The shock is not likely to be immediately fatal, because, (a) The conductors may make only a brief and imperfect contact with the body. (b) The skin, unless it is wet, offers high resistance to the current.

Hope in restoring the victim lies in prompt and continued use of artificial respiration. The reasons for this statement are: (a) The body continuously depends on an exchange of air, as shown by the fact that we must breathe in and out fifteen times a minute. (b) If the body is not thus repeatedly supplied with air, suffocation occurs. (c) Persons whose breathing has been stopped by electric shock have been restored, in some instances, after artificial respiration has been continued for an hour or more.

Instructions

1. *Break the circuit immediately;* in so doing, avoid shock to yourself.
   - (a) *Use a dry coat,* a *dry* rope, a *dry* stick or board, or any other dry non-conductor to move either the victim or the wire. Beware of using metal or any moist material. The victim's loose clothing, if dry, may be used to pull him away. Do not touch the soles or heels of his shoes. The nails are dangerous.
   - (b) *If the body must be touched by your hands,* be sure to cover them with rubber gloves, mackintosh, rubber sheeting or dry cloth; or stand on a dry board or some other dry insulating surface. If possible, use only one hand.
   - (c) *If the victim is conducting the current to the ground* and is convulsively clutching the live conductor, it

may be easier to shut off the current by lifting him than by leaving him on the ground and trying to break his grasp.

(d) *Open the nearest switch,* if that is the quickest way to break the current.

(e) *If necessary to cut a live wire,* use an ax or a hatchet with a dry, wooden handle, or properly insulated pliers.

2. *Send for the nearest doctor.*
3. *Attend instantly to the victim's breathing.*"

Instructions for Artificial Respiration

"Lay the victim on his belly, with arms extended straight forward as far as possible, and with face to one side, so that the nose and mouth are free for breathing. Let an assistant draw forward the subject's tongue. If possible, avoid so laying the subject that any burned places are pressed on. Do not permit bystanders to crowd about and shut off the fresh air. If the patient has false teeth, remove them. Pull out his tongue and wipe mucous out of mouth to allow fresh air to be drawn into his lungs.

Kneel straddling the subject's thighs and facing his head; rest the palms of your hands on the muscles of the small of the back, with thumbs nearly touching each other, and the fingers spread over the lowest ribs. With arms held straight, swing forward slowly so that the weight of your body is gradually brought to bear upon the subject. This operation, which should take from two to three seconds, should not be too violent—internal organs may be injured. The lower part of the chest and also the abdomen are thus compressed and air is forced out of the lungs. Now immediately swing backward so as to remove the pressure, but leave your hands in place, thus returning to position. The chest walls will spring out and the lungs are thus supplied with fresh air. After two seconds swing forward again. Thus repeat deliberately twelve or fifteen times a minute the double movement of compression and release. If a watch or clock is not visible, follow the natural rate of your own breathing—swing forward with each expiration and backward with each inspiration. Continue artificial respiration for an hour, if necessary, without interruption. Keep the victim warm. Do not give any liquids until conscious. Do not remove clothing that has stuck to burns, cut cloth away from around them."

APPENDIX

X-Rays

A radio operator may occasionally be called upon to assist a physician in the operation of apparatus employing vacuum tubes for the manipulation of the *radio surgical knife*, which high-frequency oscillating currents and the knife as an electrode cuts and cauterizes at the same time, or with an X-ray machine.

Figure 631 shows the construction of the well-known Crookes tube. Electrodes C and B are the cathode and anti-cathode, generally made of aluminum. The anode, A, is platinum or tungsten. This is called the "target" and bears the same relation to the other elements as the plate of a radio transmitting or receiving tube. The anti-cathode is also positive. C is negative and emits negative electrons when heated to incandescence. A regulator tube, D, contains a chemical preparation which emits a gas, when a high-potential discharge takes place through it by touching the wire E to the terminal

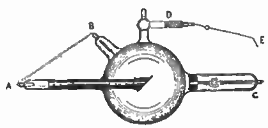


Fig. 631. Crooke's X-Ray Tube.

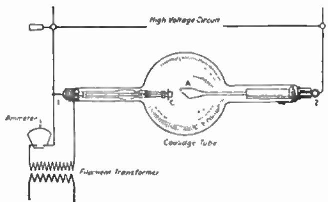


Fig. 632. Coolidge X-Ray Tube Connections.

C and drawing it away so that a spark passes between these two points. The bombardment of the concave surface of the plate A by the electrons causes the invisible rays to be thrown off. These will penetrate various substances and make a shadow picture, or *radiograph*, on a photographic plate. Figure 632 is a diagram of the connections for the Coolidge X-ray tube. The filament, C, is lighted from a step-down transformer, or from a 10 to 12-volt storage battery. A is a tungsten plate, which is fastened to a rod of molybdenum and supported by a split iron tube. The high-voltage power is obtained from the rectified output of a high-potential transformer operated on an a. c. line, or from an induction coil on a d. c. line. Figure 633 is a view of the X-ray machine manufactured by the Wappler Electric Co. of New York. This operates on a 220-volt d. c. power line, will produce a 12-inch spark in the air, and pass 150 milliamperes through the tube. Control is provided by a rheostat and taps on the primary of the induction coil transformer.

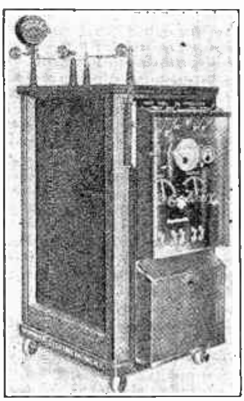


Fig. 633. Wappler X-Ray Machine.

Since the popularity of broadcast receiving, many complaints have been made about noises which have been traced to X-ray machines. On account of this it is recommended by the Bureau of Standards that X-ray machines be surrounded by metal screens to prevent radiation from the spark discharge of the apparatus, and that by-pass condensers be connected across power lines which might carry the disturbing noises. Sheet lead, lead aprons, etc., are used for protecting the operator working arounud X-ray machnies.

Greek Alphabet Symbols

LETTERS Cap.	Small	NAME	COMMONLY USED TO DESIGNATE
A	α	Alpha	Angles. Coefficients. Area.
B	β	Beta	Angles. Coefficients.
Γ	γ	Gamma	Specific gravity.
Δ	δ	Delta	Decrements. Variation. Density.
E	ε	Epsilon	Base of hyperbolic logarithms. Electromotive force.
Z	ζ	Zeta	Impedence. Co-ordinates. Coefficient.
H	η	Eta	Hysteresis coefficient. Efficiency.
Θ	θ ϑ	Theta	Angular phase displacement. Time constant.
I	ι	Iota	Current in amperes.
K	κ	Kappa	Dielectric constant. Susceptibility.
Λ	λ	Lambda	(Small) Wave lengths. Conductivity.
M	μ	Mu	Permeability. Amplification-constant. Prefix micro.
N	ν	Nu	Reluctivity.
Ξ	ξ	Xi	Output coefficienct.
O	ο	Omicron	
Π	π	Pi	3.14159, generally used as 3.1416.
P	ϱ	Rho	Resistivity.
Σ	σ ς	Sigma	(Cap) Sign of summation.
T	τ	Tau	Time constant. Time phase displacement.
Υ	υ	Upsilon	
Φ	φ	Phi	Flux. Angle of lag or lead.
X	χ	Chi	Reactance.
Ψ	ψ	Psi	Angular velocity in time. Phase difference.
Ω	ω	Omega	(Cap) Resistance in ohms. (Small) Resistance in megohms. Also $2\pi F$.

Definitions

AN AMPERE is the current which is maintained by a pressure of one volt through a resistance of one Ohm.

A VOLT is the pressure which will maintain a current of one ampere through a resistance of one Ohm.

AN OHM is the resistance which will permit one ampere of current to flow when the pressure is one volt.

A COULOMB is the quantity of current passing a given point in a circuit when there is one ampere flowing for *one second.*

A WATT is the power produced by a current of one ampere at a pressure of one volt.

A KILOWATT is one thousand watts.

A JOULE is the energy consumed by a current of one ampere under a pressure of one volt for *one second,* including the energy lost in heat.

AN AMPERE HOUR is one ampere flowing for one hour, used especially in rating of charging and discharging capacity of storage batteries.

A KILLWATT HOUR is a kilowatt of power expended for one hour, used especially for measuring power of electrical machinery and lighting systems.

A MECHANICAL FOOT-POUND is the force which will lift one pound against the force of gravity for a distance of one foot.

ONE MECHANICAL HORSEPOWER is 33,000 foot-pounds per minute, or *550 foot-pounds per second.*

ONE ELECTRIC HORSEPOWER = 746 watts, or the same power for doing work as 550 mechanical foot-pounds per second.

INDUCTION is the transfer of energy from one circuit to another by a change in the position of the conductors, or in the polarity of the inducing current.

INDUCTANCE is the property in an a. c. circuit for storing up electromagnetism.

ONE HENRY is that amount of self induction which causes an induced E. M. F. of one volt when the current in the circuit varies at the rate of one ampere per second. It is also the energy induced by the cutting of one hundred million lines of force per second.

Capacitance is the property of holding an electrostatic charge, generally referring to condensers, although there may be a capacity effect between wires or other parts of a circuit.

One Farad is that capacity which will produce a *back pressure of one volt* when the charging current is one ampere per second.

Reactance is the opposition to the flow of electricity produced in a circuit by the presence of inductance, or capacitance, or both.

Impedence is the total opposition to the flow of current, offered by the metallic resistance and the reactance combined.

A Microhm = one millionth of an ohm.

A Megohm = one million ohms.

A Microfarad = one millionth of a farad.

A Micromicrofarad = one millionth of a microfarad.

A Millihenry = one thousandth of a henry.

A Microhenry = one millionth of a henry.

A Centimeter of Inductance = L c m = one thousandth of a microhenry.

A Centimeter of Capacity = C. G. S. (centimeter—gram—second) electrostatic unit of capacity = 1.11 microfarads.

The Code

The telegraphic code used in radio communication is known as the Continental code. It is sometimes called the International Morse, on account of its being a development and modification of the original Morse code, which is still employed in land-line telegraphy in the United States. The continental code is used by all other countries over land lines, and internationally for radio work by all nations employing the roman letters in their language. Receiving and transmitting each need separate attention. It should be the ambition of every operator to be able to transmit as well as he can receive.

Transmitting the Code

The object in practicing code transmitting is to develop the ability to transmit, at a good rate of speed, signals forming intelligible communication with the person or persons for whom the communication is intended. Messages should be sent by means of clear, concise signals which the receiving operator can understand. When practicing for this purpose it is well to imagine how you would feel if you were the operator required to copy that which is being transmitted. This will help a good deal if the student is honest with himself. A practice buzzer, such as illustrated in figure 27, is often used for home practice in learning to send the code.

It is not wise to undertake to maintain any definite position of the hand for sending. This frequently prevents exactly the end desired, which is relaxation. The elbow should touch the table lightly, but should not support any of the weight of the body. Leaning on the transmitting arm causes great fatigue; and if persisted in with rigid muscles, may cause "telegrapher's paralysis." Press the first finger lightly on the disc of the key, allowing the other fingers to assume a natural and easy position. Avoid grasping the key, or cramping the hand in any manner. Do not press the wrist on the table, but keep it free to move easily. This is sometimes called a "feather grasp." The dots should be quick and snappy, and the dashes smooth and even and of the same length. The difference in speeds shows in the length of the dashes, the time between the characters, and the time between the dots and dashes composing the characters, never in the length of time required for the dots themselves. Practice slowly and carefully at first, and do not try to send rapidly until your slow sending is smooth and clear and properly spaced. The space between the letters composing a word should be three times that between the dots and dashes making up the individual letters; and the space between the words should be five times as long as that between the letters. Good transmitting has a pronounced *cadence,* or *rhythm,* something like the metre in poetry. *If the operator misses a beat the receiver feels the jar.*

Form 773 a.

DEPARTMENT OF COMMERCE
BUREAU OF NAVIGATION
RADIO SERVICE

INTERNATIONAL MORSE CODE AND CONVENTIONAL SIGNALS

TO BE USED FOR ALL GENERAL PUBLIC SERVICE RADIO COMMUNICATION

1. A dash is equal to three dots.
2. The space between parts of the same letter is equal to one dot.
3. The space between two letters is equal to three dots.
4. The space between two words is equal to five dots.

A	· —
B	— · · ·
C	— · — ·
D	— · ·
E	·
F	· · — ·
G	— — ·
H	· · · ·
I	· ·
J	· — — —
K	— · —
L	· — · ·
M	— —
N	— ·
O	— — —
P	· — — ·
Q	— — · —
R	· — ·
S	· · ·
T	—
U	· · —
V	· · · —
W	· — —
X	— · · —
Y	— · — —
Z	— — · ·

Ä (German)	· — · —
Á or Å (Spanish-Scandinavian)	· — — · —
CH (German-Spanish)	— — — —
É (French)	· · — · ·
Ñ (Spanish)	— — · — —
Ö (German)	— — — ·
Ü (German)	· · — —

1	· — — — —
2	· · — — —
3	· · · — —
4	· · · · —
5	· · · · ·
6	— · · · ·
7	— — · · ·
8	— — — · ·
9	— — — — ·
0	— — — — —

Period	· · · · · ·
Semicolon	— · — · — ·
Comma	· — · — · —
Colon	— — — · · ·
Interrogation	· · — — · ·
Exclamation point	— — · · — —
Apostrophe	· — — — — ·
Hyphen	— · · · · —
Bar indicating fraction	— · · — ·
Parenthesis	— · — — · —
Inverted commas	· — · · — ·
Underline	· · — — · —
Double dash	— · · · —
Distress Call	· · · — — — · · ·
Attention call to precede every transmission	— · — · —
General inquiry call	— · — · — — · —
From (de)	— · · ·
Invitation to transmit (go ahead)	— · —
Warning—high power	— — · · — —
Question (please repeat after......)—interrupting long messages	· · — — · ·
Wait	· — · · ·
Break (Bk.) (double dash)	— · · · —
Understand	· · · — ·
Error	· · · · · · · ·
Received (O. K.)	· — ·
Position report (to precede all position messages)	— · — ·
End of each message (cross)	· — · — ·
Transmission finished (end of work) (conclusion of correspondence)	· · · — · —

11—6860

The Continental Code.

Learning to Receive the Code

When beginning to learn the code, the groups of dots and dashes representing the different letters must first be memorized. When this has been done, a good method is to cover the letters on the code sheet with a piece of paper and try to read the dots and dashes, naming the letter for which they stand. After the code letters have been memorized visually, one must learn to recognize the sounds of them. We have seen a system recommended in which one learned the letters "by opposites": for instance, L is opposite of F, etc. We do not believe in this. It is unnecessary, and frequently confuses and hinders, rather than helps the student. One of the best ideas which has come to us along this line was the statement of a middle-aged pupil who remarked that the letters reminded him of "little bird songs," and that the individual letters of the code were as different as the song of the thrush, the nightingale and the whippoorwill. We recommend simply learning the letters by the sound or "tune" of the individual groups of dots and dashes.

A	· —
B	— · · ·
C	· · ·
D	— · ·
E	·
F	· — ·
G	— — ·
H	· · · ·
I	· ·
J	— · — ·
K	— · —
L	——
M	— —
N	— ·
O	· ·
P	· · · · ·
Q	· · — ·
R	· · ·
S	· · ·
T	—
U	· · —
V	· · · —
W	· — —
X	· — · ·
Y	· · · ·
Z	· · · ·
&	· · · ·

1	· — — ·
2	· · — · ·
3	· · · — ·
4	· · · · —
5	— — —
6	· · · · · ·
7	— — · ·
8	— · · · ·
9	— · · —
0	———

Period	· · — — · ·
Colon	— · — · ·
Colon Dash	— · — · — · ·
Semi-colon	· · · · ·
Comma	· — · —
Interrogation	— · · — ·
Exclamation	— — — ·
Fraction Line	·
Dash	— · · · — · ·
Hyphen	· · · · · — · ·
Apostrophe	· · — · · — · ·
Dollar Mark	· · · · — · ·
Pound Sterling	· · · · · · — · ·
Shilling Mark	· · — —
Pence Mark	· · · · ·
Capital Letter	· · · · — · ·
Colon Followed by Quotation	— · — · · — ·
Cents	· · ·
Decimal Point	— · · · · —
Paragraph	— — — —
Italics or Underline	· · — · — · ·
Parenthesis	· · · · · — ·
Brackets	— · · · · — · ·
Quotation	· · — · — ·
Quotation in Quotation	· · — · · — · ·
Per Cent	—— · ——

Morse Telegraph Code.

JAPANESE TELEGRAPH CODE

A	--.--	ア	ZA	-.-.- ..	ザ	HA	-...	ハ	YA	.--	ヤ
I	.-	イ	ZHI	--.-. ..	ジ	HI	--..-	ヒ	I	.-	イ
U	..-	ウ	ZU	---.- ..	ズ	HU	--..	フ	YU	-..--	ユ
E	-.---	エ	ZE	.---. ..	ゼ	HE	.	ヘ	E	-.---	エ
O	.-...	オ	ZO	---. ..	ゾ	HO	-..	ホ	YO	--	ヨ
KA	.-..	カ	TA	-.	タ	BA	-... ..	バ	RA	...	ラ
KI	-.-..	キ	CHI	..-.	チ	BI	--..- ..	ビ	RI	--.	リ
KU	...-	ク	TSU	.--.	ツ	BU	--.. ..	ブ	RU	-.--.	ル
KE	-.--	ケ	TE	.-.--	テ	BE	. ..	ベ	RE	---	レ
KO	----	コ	TO	..-..	ト	BO	-.. ..	ボ	TO	.-.-	ロ
GA	.-.. ..	ガ	DA	-. ..	ダ	PA	-... ..--.	パ	WA	-.-	ワ
GI	-.-.. ..	ギ	JI	..-. ..	ヂ	PI	--..- ..--.	ピ	WI	.-..-	ヰ
GU	...- ..	グ	DZU	.--. ..	ヅ	PU	--.. ..--.	プ	U	..-	ウ
GE	-.-- ..	ゲ	DE	.-.-- ..	デ	PE	. ..--.	ペ	WE	.--..	ヱ
GO	---- ..	ゴ	DO	..-.. ..	ド	PO	-.. ..--.	ポ	WO	.---	ヲ
SA	-.-.-	サ	NA	.-.	ナ	MA	-..-	マ	1	.----	一
SHI	--.-.	シ	NI	-.-.	ニ	MI	..-.-	ミ	2	..---	二
SU	---.-	ス	NU	....	ヌ	MU	-	ム	3	...--	三
SE	.---.	セ	NE	--.-	ネ	ME	-...-	メ	4	....-	四
SO	---.	ソ	NO	..--	ノ	MO	-..-.	モ	5	.....	五
									6	-....	六
N (n, ng.)	.-.-.	ン							7	--...	七
									8	---..	八
Brackets ( )	-.--.-								9	----.	九
Break	.. .. ..								0	-----	○

Japanese Code.

(This copy was furnished by Mr. T. Taketomi, secretary of the Japanese Embassy in Washington, who states that these are the "Katakana characters in common use among the people.")

Radio Operator's Licenses

Below is a copy of the first-class license for a commercial radio operator. The second-class license was for several years given to applicants for first-class licenses who passed the first-class code test but who failed within ten points of passing the first-class theory examination. This type of license is not accepted on seagoing vessels, but qualifies one

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Grade.......... No..........

THE UNITED STATES OF AMERICA.

DEPARTMENT OF COMMERCE.

Bureau of Navigation.

LICENSE TO RADIO OPERATOR, COMMERCIAL FIRST CLASS.

This is to certify that..
has been examined and passed, pursuant to the Radiotelegraphic Convention, in

(a) adjustment, operation and care of apparatus;

(b) transmitting and sound reading at a speed of not less than 20 words a minute, Continental Morse;

(c) use and care of storage battery or other auxiliary;

(d) knowledge of international regulations and Acts of Congress to regulate radio communication;

and is hereby licensed as required by law a Radio Operator, Commercial First Class, for two years. The candidate's practical knowledge of adjustment was tested on a .... set of apparatus. His knowledge of other systems is shown below.

....

....

....

.... Oath of Secrecy executed.

....
Secretary of Commerce.

....
(Examining Officer.)

....
Commissioner of Navigation.

....
(Title.) Notary Public.

Place...................... Date............192..

for operating a broadcasting station. Recently a new and more appropriate type of examination designed especially for broadcasting station operators has been devised. This includes a code test at the rate of 12 words per minute and a written examination for which a knowledge of vacuum-tube apparatus of all kinds is required. The licenses issued to those passing this test are the usual second-class license with the added inscription: "Valid for the operation of a broadcasting station."

The commercial first-class license, reproduced herewith, is printed on white paper, and is commonly referred to among operators as the "white ticket." The commercial second class, or second class license for broadcasting, is printed on yellow paper. An *extra* first class license, known as the "pink ticket," is also issued. The requirements for obtaining this are, not less than two years of experience, ability to copy and transmit Continental code at the rate of twenty-five words per minute, and a knowledge of American Morse.

A station license is always necessary for the operation of any class of transmitting station, the grading being according to the specifications and type of transmitting work to be done.

The following is a copy of the amateur first-grade license. For this it is required that the applicant pass a code test of not less than 10 words per minute, and a written theory examination covering questions on elementary electricity, and diagrams of the transmitting and receiving apparatus to be used in the prospective amateur station, with constants and wave length.

The amateur first grade license is blue. There is also an amateur second class, or provisional, license. This is issued temporarily to applicants who are unable to pass the examination for the amateur first class license, but who have shown that they have a knowledge of the laws regarding interference, etc. This is a small white certificate.

No............

THE UNITED STATES OF AMERICA.
DEPARTMENT OF COMMERCE.
Bureau of Navigation.

LICENSE TO RADIO OPERATOR, AMATEUR FIRST GRADE.

This is to certify that ....has been examined and shown to have a knowledge of the adjustment and operation of apparatus and of the regulations of the Radiotelegraphic Convention and the Acts of Congress in so far as they relate to interference with radio communication and impose certain duties on all grades of operators sufficient to entitle him to a license, and he is hereby licensed as required by law Radio Operator, Amateur First Grade, for two years.

The candidate was examined and shown to have knowledge (excellent or good) in the following additional subjects:

(a) general adjustment, operation and care of apparatus........:

(b) transmitting and sound reading Continental Morse at a speed of........words a minute;

(c) general knowledge of international regulations and Acts of Congress to regulate radio communication.........................

.... Oath of Secretary executed.
(Examining Officer.)

....
(Title.) Notary Public.

Place............................., Date................., 192...

....
Secretary of Commerce.

....
Commissioner of Navigation.

Operators' licenses are not valid until the following oath has been executed on the backs of the licenses.

I, ..., do solemnly swear that I will faithfully preserve the secrecy of all messages coming to my knowledge through my employment under this license; that this obligation is taken freely, without mental reservation or purpose of evasion; and that I will well and faithfully discharge the duties of the office: So help me God.

....

(Signature of holder.)

Date of birth, ... Place of birth, ...

Sworn to and subscribed before me this.........................

day of............................. A. D., 192...

....

[Seal.] Notary Public.

ADDRESSES OF SUPERVISORS OF RADIO, JUNE, 1926

Charles C. Kolster, 1st District, Customhouse, Boston, Mass.
Arthur Batchelder, 2nd District, Sub-Treasury Bldg., New York, N. Y.
R. Y. Cadmus, 3rd District, Customhouse, Baltimore, Md.
Walter Van Nostrand, Jr., 4th District, 524 Postoffice Bldg., Atlanta, Ga.
Theodore G. Deiler, 5th District, Customhouse, New Orleans, La.
John F. Dillon, 6th District, Customhouse, San Francisco, Cal.
O. R. Redfern, 7th District, 2116 L. C. Smith Bldg., Seattle, Wash.
S. W. Edwards, 8th District, Federal Bldg., Detroit, Mich.
E. A. Beane, 9th District, Federal Bldg., Chicago, Ill.

Examinations for licenses are given in the offices of Supervisors, and also in offices of several radio inspectors under these supervisors in each district. The addresses of the nearest radio inspector's office may be obtained from the supervisor of that district.

Examinations for amateur licenses are given in the office of the Chief Radio Inspector, Commerce Bldg., Washington, D. C.

In the territories examinations are held in the following places:

Naval Radio Stations: San Juan, P. R.; Colon, Canal Zone; Honolulu, Hawaii.

United States Army Stations: Fort St. Michael, Alaska; For Valdez, Alaska.

MEASURE OF CIRCULAR MOTION FOR LATITUDE AND LONGITUDE

60 seconds, 60″ = 1 minute.
60 minutes, 60′ = 1 degree, or °.
30 degrees ..... = 1 sign.
90 degrees..... = 1 quadrant, or right angle.
12 signs, 360° . = 1 great circle of the zodiac.

CIRCLE

The ratio of the circumference of a circle to its diameter is 3.1416, or π.

Circumference = d × 3.1416
Area of circle = $d^2 \times .7854$

$$(.7854 = \frac{\pi}{4})$$

Area of a circle also = $r^2 \pi$

METRIC SYSTEM

Measures of *Length*

Myriameter.. 10,000 meters, 6.2137 miles.
Kilometer.... 1,000 meters, .62137 mile, or 3,280 feet 1 inch.
Hectometer .. 100 meters, 328 feet 1 inch.
Dekameter... 10 meters, 393.7 inches.
Meter .... 1 meter, 39.37 inches.
Decimeter....1 meter, 3.937 inches.
Centimeter... .01 meter, 0.3937 inches.
Millimeter .... .001 meter, 0.03937 inches.

Metric Measure of Surfaces

Hectare.. 10,000 sq. meters, 2.471 acres.
Are...... 100 sq. meters, 119.6 sq. yards.
Centare.. 1 sq. meter, 1550 sq. inches.

5280 feet = 1 mile.
1760 yds. = 1 mile.
1609.34 meters = 1 mile.

INVOLUTION AND EVOLUTION

(From Payne's Practical Arithmetic.)

"*Involution* is the process of finding the powers of numbers. A *power* of a number is the product arising from using a number one or more times as a factor. *The first* power of a number is the number itself. The *second* power, or *square* of the number is the product arising from taking the number *twice* as a factor. $5^2 = 5 \times 5 = 25$. The *third* power or *cube* of a number is the product arising from taking the number three times as a factor. $5^3 = 5 \times 5 \times 5 = 125$. The *base* is the number whose power is to be found. The *exponent* is the small figure placed a little above and to the right of another to show how many times the number is to be used as a factor.

"*Evolution* is the process of finding roots of numbers, hence it is the reverse of involution. A *root* of a number is one of the factors of that number. $5 \times 5 \times 5 = 125$, hence 5 is a root of 125. The *square root* of a number is one of the two *equal* factors of that number. $5 \times 5 = 25$, hence the *square root* of 25 is 5. The *cube root* of a number is one of the *three* equal factors of that number. $3 \times 3 \times 3 = 27$, hence 3 is the cube root of 27. A root is indicated by the character $\surd$, originally r, meaning radius or root, and called a radical sign. An index is a small number placed over the radical sign to denote the degree of the root. If no number is so placed the square root is understood.

Rule for Square Root of Large Numbers

"Rule 1.—To extract the square root, begin with units and separate the number into periods of two figures each, placing a dot over the right hand figure of each period.

Find the largest square that can be subtracted from the left hand period, and place the root at the right as a quotient in division. Subtract the square from the left hand period and to the remainder annex the next period for a new dividend.

Double the root found and place it at the left for a trial divisor. Find how many times this devisor is contained in the dividend exclusive of the right hand figure. Place the quotient in the root and also at the right of the trial divisor.

Multiply the complete divisor by the last root figure, subtract the product from the dividend, and to the remainder annex the next period for a new dividend.

Double the root found, place it at the left for a trial divisor, and proceed as before until all the periods have been used.

If at any time the dividend, exclusive of the right hand figure, will not contain the trial devisor, place a cipher in the quotient and also to the right of the trial divisor, annex another period to the dividend, and proceed as before.

"Rule 2.—To extract the square root of a decimal, begin at the decimal point and separate the number into periods of two figures each, annexing a cipher if necessary to fill out a period.

Extract the square root as in integers and point off as many decimal places in the root as there are decimal periods in the dividend."

For two other methods of working square root, known as the *analytical method* and the *factoring method,* see any standard arithmetic.

EXAMPLE.—Extract the square root of 1280304.16

```
Form:  1'28'03'04 .16 (1131.505262
       1
      -----
 21)  28
      21
      -----
 223)  703
       669
       -----
 2261)  3404
        2261
        -------
 22625) 114316
         113125
         -------
 2263005)  11910000
           11315025
           ---------
 22630102)   59497500
             45260204
             ----------
 226301046)  1423729600
             1357806276
             ----------
 2263010522)   6592332400
               4526021044
               ----------
               2066311356
```

EVOLUTION

No.	Square	Cube	Fifth Power	No.	Square	Cube	Fifth Power
1.0	1.00	1.000	1.0000	5.5	30.25	166.375	5,032.8
1.1	1.21	1.331	1.6105	5.6	31.36	175.616	5,507.3
1.2	1.44	1.728	2.4883	5.7	32.49	185.193	6,016.9
1.3	1.69	2.197	3.7129	5.8	33.64	195.112	6,563.6
1.4	1.96	2.744	5.3782	5.9	34.81	205.379	7,149.2
1.5	2.25	3.375	7.5938	6.0	36.00	216.000	7,776.0
1.6	2.56	4.096	10.486	6.1	37.21	226.981	8,446.0
1.7	2.89	4.913	14.199	6.2	38.44	238.328	9,161.3
1.8	3.24	5.832	18.896	6.3	39.69	250.047	9,924.4
1.9	3.61	6.859	24.761	6.4	40.96	262.144	10,737
2.0	4.00	8.000	32.000	6.5	42.25	274.625	11,603
2.1	4.41	9.261	40.841	6.6	43.56	287.496	12,523
2.2	4.84	10.648	51.536	6.7	44.89	300.763	13,501
2.3	5.29	12.167	64.363	6.8	46.24	314.432	14,539
2.4	5.76	13.824	79.626	6.9	47.61	328.509	15,640
2.5	6.25	15.625	97.656	7.0	49.00	343.000	16,807
2.6	6.76	17.576	118.81	7.1	50.41	357.911	18,042
2.7	7.29	19.683	143.49	7.2	51.84	373.248	19,349
2.8	7.84	21.952	172.10	7.3	53.29	389.017	20,731
2.9	8.41	24.389	205.11	7.4	54.76	405.224	22,190
3.0	9.00	27.000	243.00	7.5	56.25	421.875	23,730
3.1	9.61	27.791	286.29	7.6	57.76	438.976	25,355
3.2	10.24	32.768	335.54	7.7	59.29	456.533	27,068
3.3	10.89	35.937	391.35	7.8	60.84	474.552	28,872
3.4	11.56	39.304	454.35	7.9	62.41	493.039	30,771
3.5	12.25	42.875	525.22	8.0	64.00	512.000	32,768
3.6	12.96	46.656	604.66	8.1	65.61	531.441	34,868
3.7	13.69	50.653	693.44	8.2	67.24	551.368	37,074
3.8	14.44	54.872	792.35	8.3	68.89	571.787	39,390
3.9	15.21	59.319	902.24	8.4	70.56	592.704	41,821
4.0	16.00	64.000	1,024.0	8.5	72.25	614.125	44,371
4.1	16.81	68.921	1,158.6	8.6	73.96	636.056	47,043
4.2	17.64	74.088	1,306.9	8.7	75.69	658.503	49,842
4.3	18.49	79.507	1,470.1	8.8	77.44	681.472	52,773
4.4	19.36	85.184	1,649.2	8.9	79.21	704.969	55,841
4.5	20.25	91.125	1,845.3	9.0	81.00	729.000	59,041
4.6	21.16	97.336	2,059.6	9.1	82.81	753.571	62,403
4.7	22.09	103.823	2,293.5	9.2	84.64	778.688	65,908
4.8	23.04	110.592	2,548.0	9.3	86.49	804.357	69,569
4.9	24.01	117.649	2,824.8	9.4	88.36	830.584	73,390
5.0	25.00	125.000	3,125.0	9.5	90.25	857.375	77,378
5.1	26.01	132.651	3,450.3	9.6	92.16	884.736	81,537
5.2	27.04	140.608	3,802.1	9.7	95.09	912.673	85,873
5.3	28.09	148.877	4,182.0	9.8	96.04	941.192	90,392
5.4	29.16	157.464	4,591.7	9.9	98.01	970.299	95,099

Logarithms

The Briggs, or common logarithm, on base 10, is shown in the accompanying table. See paragraph 214. By the logarithm of a number is meant the *power* to which another number, referred to as the base, must be raised to equal the number in question. For instance, with 10 as a base, the logarithm of 100 is 2, because 10 must be squared to equal 100, or log 100 = 2. Tables of logarithms are constructed on the base 10, and are known as common logarithms. To convert the common logarithm of a number to the Naperian,

SIMPLIFIED TABLE OF COMMON LOGARITHMS

N	0	1	2	3	4	5	6	7	8	9
10	000	004	009	013	017	021	025	029	033	037
11	041	045	049	053	057	061	064	068	072	076
12	079	083	086	090	093	097	100	104	107	111
13	114	117	121	124	127	130	134	137	140	143
14	146	149	152	155	158	161	164	167	170	173
15	176	179	182	185	188	190	193	196	199	201
16	204	207	210	212	215	217	220	223	225	228
17	230	233	236	238	241	243	246	248	250	253
18	255	258	260	262	265	267	270	272	274	276
19	279	281	283	286	288	290	292	294	297	299
20	301	303	305	307	310	312	314	316	318	320
21	322	324	326	328	330	332	334	336	338	340
22	342	344	346	348	350	352	354	356	358	360
23	362	364	365	367	369	371	373	375	377	378
24	380	382	384	386	387	389	391	393	394	396
25	398	400	401	403	405	407	408	410	412	413
26	415	417	418	420	422	423	425	427	428	430
27	431	433	435	436	438	439	441	442	444	446
28	447	449	450	452	453	455	456	458	459	461
29	462	464	465	467	468	470	471	473	474	476
30	477	479	480	481	483	484	486	487	489	490
31	491	493	494	496	497	498	500	501	502	504
32	505	507	508	509	511	512	513	515	516	517
33	519	520	521	522	524	525	526	528	529	530
34	531	533	534	535	537	538	539	540	542	543
35	544	545	547	548	549	550	551	553	554	555
36	556	558	559	560	561	562	563	565	566	567
37	568	569	571	572	573	574	575	576	577	579
38	580	581	582	583	584	585	587	588	589	590
39	591	592	593	594	595	597	598	599	600	601
40	602	603	604	605	606	607	609	610	611	612
41	613	614	615	616	617	618	619	620	621	622
42	623	624	625	626	627	628	629	630	631	632
43	634	635	636	637	638	639	640	641	642	643
44	643	644	645	646	647	648	649	650	651	652
45	653	654	655	656	657	658	659	660	661	662
46	663	664	665	666	667	667	668	669	670	671
47	672	673	674	675	676	677	678	679	679	680
48	681	682	683	684	685	686	687	688	688	689
49	690	691	692	693	694	695	695	696	697	698

or natural logarithm, of which the base is 2.7183, multiply the common logarithm by 2.3026, which is the log of the base 2.7183 to 10. To convert any Naperian logarithm to a common logarithm multiply it by 0.4343. The base of the nat-

SIMPLIFIED TABLE OF COMMON LOGARITHMS—Continued

N	0	1	2	3	4	5	6	7	8	9
50	699	700	701	702	702	703	704	705	706	707
51	708	708	709	710	711	712	713	713	714	715
52	715	717	718	719	719	720	721	722	723	723
53	724	725	726	727	728	728	729	730	731	732
54	732	733	734	735	736	736	737	738	739	740
55	740	741	742	743	744	744	745	746	747	747
56	748	749	750	751	751	752	753	754	754	755
57	756	757	757	758	759	760	760	761	762	763
58	763	764	765	766	766	767	768	769	769	770
59	771	772	772	773	774	775	775	776	777	777
60	778	779	780	780	781	782	782	783	784	785
61	785	786	787	787	788	789	790	790	791	792
62	792	793	794	794	795	796	797	797	798	799
63	799	800	801	801	802	803	803	804	805	806
64	806	807	808	808	809	810	810	811	812	812
65	813	814	814	815	816	816	817	818	818	819
66	820	820	821	822	822	823	823	824	825	825
67	826	827	827	828	829	829	830	831	831	832
68	833	833	834	834	835	836	836	837	838	838
69	839	839	840	841	841	842	843	843	844	844
70	845	846	846	847	848	848	849	849	850	851
71	851	852	852	853	854	854	855	856	856	857
72	857	858	859	859	860	860	861	862	862	863
73	863	864	865	865	866	866	867	867	868	869
74	869	870	870	871	872	872	873	873	874	874
75	875	876	876	877	877	878	879	879	880	880
76	881	881	882	883	883	884	884	885	885	886
77	887	887	888	888	889	889	890	890	891	892
78	892	893	893	894	894	895	895	896	897	897
79	898	898	899	899	900	900	901	901	902	903
80	903	904	904	905	905	906	906	907	907	908
81	909	909	910	910	911	911	912	912	913	913
82	914	914	915	915	916	916	917	918	918	919
83	919	920	920	921	921	922	922	923	923	924
84	924	925	925	926	926	927	927	927	928	929
85	929	930	930	931	931	932	932	933	933	934
86	935	935	936	936	937	937	938	938	939	939
87	940	940	941	941	942	942	943	943	943	944
88	945	945	945	946	946	947	947	948	948	949
89	949	950	950	951	951	952	952	952	953	954
90	954	955	955	956	956	957	957	958	958	959
91	959	960	960	960	961	961	962	962	963	963
92	964	964	965	965	966	966	967	967	968	968
93	968	969	969	970	970	971	971	972	972	973
94	973	974	974	975	975	975	976	976	977	977
95	978	978	979	979	980	980	980	981	981	982
96	982	983	983	984	984	985	985	985	986	986
97	987	987	988	988	989	989	989	990	990	991
98	991	992	992	993	993	993	994	994	995	995
99	996	996	997	997	997	998	998	999	999	000

ural logarithms is usually represented by the letter ε. Logarithms of perfect powers of 10 have no decimals, but most logarithms contain decimals. The decimal part of the logarithm is called the *mantissa,* and the part at the left of the decimal point the *characteristic.* In the accompanying table the numbers 0, 1, 2, 3, 4, 5, 6, 7, 8, 9 are seen across the top, and numbers from 10 to 99 down the left-hand side. The numbers across the top of the table are the right-hand figures of the numbers whose left-hand figures are at the left-hand side of the table; and the figures under the numbers across the top are the mantissas of these numbers. For instance, suppose it is desired to find the log of 3820. We find the mantissa of 382, which will be the same as for 3820. This is .582. As the number 3820 contains four figures, its characteristic is 3. Therefore the log of 3820 is 3.582.

TABLE FOR CONVERTING COMMON LOGARITHMS INTO NATURAL LOGARITHMS

Common	Natural	Common	Natural	Common	Natural	Common	Natural
0	0.0000	25.0	57.565	50.0	115.129	75.0	172.694
1.0	2.3026	26.0	59.867	51.0	117.432	76.0	174.996
2.0	4.6052	27.0	62.170	52.0	119.734	77.0	177.299
3.0	6.9078	28.0	64.472	53.0	122.037	78.0	179.602
4.0	9.2103	29.0	66.775	54.0	124.340	79.0	181.904
5.0	11.513	30.0	69.078	55.0	126.642	80.0	184.207
6.0	13.816	31.0	71.380	56.0	128.945	81.0	186.509
7.0	16.118	32.0	73.683	57.0	131.247	82.0	188.812
8.0	18.421	33.0	75.985	58.0	133.550	83.0	191.115
9.0	20.723	34.0	78.288	59.0	135.853	84.0	193.417
10.0	23.026	35.0	80.590	60.0	138.155	85.0	195.720
11.0	25.328	36 0	82.893	61.0	140.458	86.0	198.022
12.0	27.631	37.0	85.196	62.0	142.760	87.0	200.325
13.0	29.934	38.0	87.498	63.0	145.063	88.0	202.627
14.0	32.236	39.0	89.801	64.0	147.365	89.0	204.930
15.0	34.539	40.0	92.103	65.0	149.668	90.0	207.233
16.0	36.841	41.0	94.406	66.0	151.971	91.0	209.535
17.0	39.144	42.0	96.709	67.0	154.273	92.0	211.838
18.0	41.447	43.0	99.011	68.0	156.576	93.0	214.140
19.0	43.749	44.0	101.314	69.0	158.878	94.0	216.443
20.0	46.052	45.0	103.616	70.0	161.181	95.0	218.746
21.0	48.354	46.0	105.919	71.0	163.484	96.0	221.048
22.0	50.657	47.0	108.221	72.0	165.786	97.0	223.351
23.0	52.959	48.0	110.524	73.0	168.089,	98.0	225.653
24.0	55.262	49.0	112.827	74.0	170.391	99.0	227.956
						100.0	230.259

TABLE OF EQUIVALENTS FOR ELECTRICAL POWER AND HEATING.

(By H. Ward Leonard, Electrical Engineer.)

Unit	Equivalent in other units.
1 k. w.	1000 Watts 1.34 Horse power 2,654,200 foot lbs., per hour. 44,240 foot lbs. per minute. 737.3 foot lbs. per second. 3,412 heat units per hour. 56.9 heat units per minute. .948 heat units per second. .2275 lbs. coal oxidized per hour. 3.53 lbs. water evaporated per hour at 212° Fahrenheit.
1 k. w. Hour	1000 Watt hours. 1.34 Horse Power hours. 2,654,200 foot lbs. 3,600,000 joules. 3,412 heat units. 367,000 Kilogram meters. .229 lbs. coal oxidized with perfect efficiency. 3.53 lbs. of water evaporated at 212° Fahrenheit. 22.75 lbs. of water raised from 62° to 212° Fahrenheit. 8 cents at usual rates of electric heating.
1 H. P.	746 Watts. .746 K. W. 33,000 foot lbs. per minute. 550 foot lbs. per second. 2,545 heat units per hour. 42.4 heat units per minute. .707 heat units per second. .175 lbs. coal oxidized per hour. 2.64 lbs. water evaporated per hour at 212° Fahrenheit.
1 H. P. Hour	.746 K. W. hours. 1,980,000 foot lbs. 2,545 heat units. 273,740 Kilogram meters. 175 lbs. coal oxidized with perfect efficiency. 17.0 lbs. water raised from 62° to 212° Fahrenheit. 2.64 lbs. water evaporated at 212° Fahrenheit. 6 cents at usual rates of ele trio heating.

TABLE OF EQUIVALENTS FOR
ELECTRICAL POWER AND HEATING—CONTINUED

Unit	Equivalent to other units
1 Joule	1 Watt second. .00000278 K. W. hour. 102 Kilogram meters. .0009477 heat units. .7373 foot lbs.
1 Foot lb.	1.356 joules. .1383 Kilogram meters. .000000377 K. W. hours. .0001285 heat units. .0000005 H. P. hours.
1 Watt	1 joule per second. .00134 H. P. .001 K. W. 3.412 heat units per hour. .7373 foot lbs. per second. .003 lbs. of water evaporated per hour. 44.24 foot lbs. per minute.
1 Heat Unit	1055 Watt seconds. 778 foot lbs. .252 calorie. 107.6 Kilogram meters. .000293 K. W. hour. .000393 H. P. hours. .0000688 lbs. coal oxidized. .001036 lbs. water evaporated at 212° Fahrenheit.
1 Kilogram Meter	7.23 foot lbs. .00000366 H. P. hours. .00000272 K. W. hours. .0093 heat units.

NICHROME RESISTANCE WIRE

Driver-Harris Co., Harrison, N. J.

Specific resistance, 660 ohms per circular mil-foot at 20° C. (68° F.)
Temperature coefficient, 0.0002 per degree Centigrade, between 20° C. and 100° C.

No. B. & S.	Dia. in Inches	Ohms. Per 1,000 Ft. at 20° C.	Weight Per 1,000 Ft. Bare Wire Pounds	Feet Per Pound Bare Wire	Price Per Pound Bare Wire	No. B. & S.	Dia. in Inches (Cont.)	Price Per Pound Bare Wire
1	.289	7.9	231.0	4.33	$2.70	....	.00275	$32.00
2	.258	9.9	184.0	5.43	2.70	....	.0025	40.00
3	.229	12.6	145.0	6.90	2.70	....	.00225	50.00
4	.204	15.9	115.0	8.70	2.70	....	.002	60.00
5	.182	19.9	92.0	10.9	2.70	....	.00175	75.00
6	.162	25.1	73.0	13.7	2.70	....	.0015	95.00
7	.144	31.8	57.0	17.5	2.70	7	....	....
8	.1285	40.3	45.0	22.2	2.70	8	....	....
9	.114	50.8	36.0	27.8	2.74	9	....	....
10	.102	63.4	29.0	34.5	2.78	10	....	....
11	.091	79.7	23.0	43.5	2.82	11	....	....
12	.081	100.6	18.0	55.6	2.88	12	....	....
13	.072	127.3	14.3	69.9	2.94	13	....	....
14	.064	161.1	11.3	88.5	3.00	14	....	....
15	.057	203.0	9.2	109.0	3.06	15	....	....
16	.051	254.0	7.2	139.0	3.12	16	....	....
17	.045	326.0	5.6	179.0	3.20	17	....	....
18	.040	412.0	4.42	226.0	3.30	18	....	....
19	.036	509.0	3.58	279.0	3.45	19	....	....
20	.032	645.0	2.83	353.0	3.60	20	....	....
21	.0285	813.0	2.24	446.0	3.80	21	....	....
22	.0254	1,031.0	1.77	565.0	4.10	22	....	....
23	.0226	1,292.0	1.41	709.0	4.40	23	....	....
24	.0201	1,634.0	1.12	893.0	4.80	24	....	....
25	.0179	2,060.0	0.89	1,123.0	5.20	25	....	....
26	.0159	2,611.0	0.70	1,429.0	5.60	26	....	....
27	.0142	3,274.0	0.56	1,786.0	6.00	27	....	....
28	.0126	4,159.0	0.44	2,273.0	6.40	28	....	....
29	.0113	5,168.0	0.35	2,857.0	6.80	29	....	....
30	.0100	6,600.0	0.276	3,623.0	7.20	30	....	....
31	.0089	8,333.0	0.219	4,566.0	7.60	31	....	....
32	.0080	10,313.0	0.177	5,650.0	8.00	32	....	....
33	.0071	13,098.0	0.139	7,194.0	8.60	33	....	....
34	.0063	16,623.0	0.110	9,091.0	9.40	34	....	....
35	.0056	21,019.0	0.087	11,490.0	10.50	35	....	....
36	.0050	26,400.0	0.069	14,490.0	12.00	36	....	....
37	.0045	32,672.0	0.056	17,860.0	14.00	37	....	....
38	.0040	41,240.0	0.045	22,220.0	17.00	38	....	....
39	.0035	54,098.0	0.034	29,410.0	21.00	39	....	....
40	.0031	73,333.0	0.025	40,000.0	26.00	40	....	....

CURRENT TEMPERATURE CHARACTERISTICS OF NICHROME RESISTANCE WIRE

Driver-Harris Co., Harrison, N. J.

Showing amperes necessary for a given temperature.
Applying only to straight wires stretched horizontally in free air.

No. B. & S.	Dia. in Inches	100°C. 212°F.	200° C. 392° F.	300° C. 572° F.	400° C. 752° F.	500° C. 932° F.	600° C. 1112° F.	700° C. 1292° F.	800° C. 1472° F.	900° C. 1652° F.	1000° C. 1832° F.	1100° C. 2012° F.
1	.289	54.2	100.0	136.0	169.0	201.0	225.0	254.0	280.0	308.0	334.0	359.0
2	.258	45.9	84.5	115.0	143.0	170.0	191.0	215.0	237.0	261.0	283.0	304.0
3	.229	38.9	71.5	97.5	121.5	144.0	162.0	182.0	201.0	221.0	240.0	258.0
4	.204	33.0	60.6	82.6	103.0	122.0	137.0	154.0	170.0	187.0	203.0	219.0
5	.182	28.0	51.4	70.0	87.0	103.0	116.0	130.0	144.0	158.0	172.0	185.0
6	.162	23.8	43.5	59.4	73.7	87.4	98.7	110.0	122.0	134.0	146.0	157.0
7	.144	20.2	36.8	50.3	62.5	74.0	83.7	93.5	104.0	113.0	124.0	133.0
8	.1285	17.1	31.2	42.6	53.0	62.6	71.0	79.2	87.6	96.2	105.0	113.0
9	.114	14.5	26.4	36.1	44.8	53.0	60.0	67.1	74.3	81.5	88.7	96.0
10	.102	12.3	22.4	30.6	38.0	44.8	51.2	57.0	63.1	68.8	75.1	81.2
11	.091	10.4	19.0	25.9	32.2	38.0	43.4	48.3	53.5	58.3	63.6	68.8
12	.081	8.80	16.1	22.0	27.3	32.1	36.8	40.8	45.3	49.4	53.9	58.3
13	.072	7.45	13.6	18.6	23.1	27.2	31.0	34.6	38.4	41.9	45.7	49.4
14	.064	6.31	11.5	15.8	19.6	23.0	26.2	29.3	32.4	35.5	38.7	41.9
15	.057	5.35	9.77	13.4	16.6	19.5	22.3	24.8	27.6	30.2	32.3	35.5
16	.051	4.54	8.28	11.35	14.1	16.5	18.9	21.0	23.4	25.6	27.4	30.1
17	.045	3.85	7.02	9.60	12.0	14.0	16.0	17.8	19.8	21.7	23.2	25.5
18	.040	3.26	5.95	8.13	10.1	11.8	13.6	15.1	16.8	18.4	19.9	21.6
19	.036	2.76	5.04	6.88	8.60	10.1	11.55	12.8	14.2	15.6	16.9	18.3
20	.032	2.32	4.27	5.83	7.30	8.53	9.70	10.85	12.0	13.2	14.3	15.5
21	.0285	1.97	3.62	4.94	6.17	7.23	8.21	9.20	10.2	11.2	12.2	13.1
22	.0254	1.67	3.07	4.18	5.23	6.13	6.96	7.80	8.65	9.46	10.3	11.1
23	.0226	1.42	2.60	3.54	4.43	5.19	5.90	6.61	7.33	8.02	8.73	9.44
24	.0201	1.20	2.20	3.00	3.75	4.40	5.00	5.60	6.20	6.80	7.40	8.00
25	.0179	1.02	1.86	2.54	3.18	3.73	4.25	4.67	5.27	5.76	6.27	6.78
26	.0159	.865	1.58	2.15	2.70	3.16	3.61	3.96	4.47	4.88	5.31	5.74
27	.0142	.734	1.34	1.82	2.28	2.68	3.06	3.36	3.80	4.13	4.50	4.86
28	.0126	.622	1.13	1.54	1.85	2.27	2.62	2.86	3.23	3.50	3.81	4.12
29	.0113	.527	.960	1.305	1.57	1.93	2.22	2.45	2.71	2.97	3.23	3.50
30	.0100	.447	.814	1.105	1.33	1.64	1.89	2.08	2.30	2.52	2.74	2.97
31	.0089	.378	.680	.935	1.13	1.39	1.60	1.77	1.95	2.14	2.32	2.52
32	.0080	.321	.577	.791	.955	1.18	1.36	1.50	1.66	1.81	1.97	2.14
33	.0071	.272	.490	.670	.809	1.00	1.15	1.28	1.41	1.53	1.67	1.81
34	.0063	.231	.416	.567	.685	.849	.980	1.06	1.18	1.29	1.41	1.52
35	.0056	.196	.353	.480	.580	.720	.830	.90	1.00	1.09	1.19	1.29
36	.0050	.166	.300	.406	.491	.611	.704	.765	.850	.924	1.01	1.09
37	.0045	.141	.254	.344	.416	.518	.597	.650	.721	.783	.856	.924
38	.0040	.120	.216	.291	.352	.440	.507	.552	.613	.663	.725	.783
39	.0035	.101	.183	.246	.298	.373	.430	.467	.517	.566	.617	.667
40	.0031	.085	.155	.208	.252	.316	.364	.396	.439	.480	.523	.565

COMPARATIVE TABLE OF GAUGES

Gauge No.	American Wire Gauge (Brown & Sharpe)		Birmingham Wire Gauge (Stubs)		Standard Wire Gauge (British)	
	Diameter	Area	Diameter	Area	Diameter	Area
	Inches	Circular Mils	Inches	Circular Mils	Inches	Circular Mils
7-0	....	....	...	...	0.500	250000.
6-0	....	....	...	....	0.464	215300.
5-0	....	....	...	....	0.432	186600.
4-0	0.4600	211600.	0.454	206100.	0.400	160000.
3-0	0.4096	167800.	0.425	180600.	0.372	138400.
2-0	0.3648	133100.	0.380	144400.	0.348	121100.
0	0.3249	105500.	0.340	115600.	0.324	105000.
1	0.2893	83690.	0.300	90000.	0.300	90000.
2	0.2576	66370.	0.284	80660.	0.276	76180.
3	0.2294	52630.	0.259	67080.	0.252	63500.
4	0.2043	41740.	0.238	56640.	0.232	53820.
5	0.1819	33100.	0.220	48400.	0.212	44940.
6	0.1620	26250.	0.203	41210.	0.192	36860.
7	0.1443	20820.	0.180	32400.	0.176	30980.
8	0.1285	16510.	0.165	27230.	0.160	25600.
9	0.1144	13090.	0.148	21900.	0.144	20740.
10	0.1019	10380.	0.134	17960.	0.128	16380.
11	0.09074	8234.	0.120	14400.	0.116	13460.
12	0.08081	6530.	0.109	11880.	0.104	10820.
13	0.07196	5178.	0.0950	9025.	0.092	8464.
14	0.06408	4107.	0.0830	6889.	0.080	6400.
15	0.05707	3257.	0.0720	5184.	0.072	5184.
16	0.05082	2583.	0.0650	4225.	0.064	4096.
17	0.04526	2048.	0.0580	3364.	0.056	3136.
18	0.04030	1624.	0.0490	2401.	0.048	2304.
19	0.03589	1288.	0.0420	1764.	0.040	1600.
20	0.03196	1022.	0.0350	1225.	0.036	1296.
21	0.02846	810.1	0.0320	1024.	0.032	1024.
22	0.02535	642.4	0.0280	784.	0.028	784.0
23	0.02257	509.5	0.0250	625.	0.024	576.0
24	0.02010	404.0	0.0220	484.	0.022	484.0
25	0.01790	320.4	0.0200	400.	0.020	400.0
26	0.01594	254.1	0.0180	324.	0.018	324.0
27	0.01420	201.5	0.0160	256.	0.0164	269.0
28	0.01264	159.8	0.0140	196.	0.0148	219.0
29	0.01126	126.7	0.0130	169.	0.0136	185.0
30	0.01003	100.5	0.0120	144.	0.0124	153.8
31	0.008928	79.70	0.0100	100.	0.0116	134.6
32	0.007950	63.21	0.0090	81.	0.0108	116.6
33	0.007080	50.13	0.0080	64.	0.0100	100.0
34	0.006305	39.75	0.0070	49.	0.0092	84.64
35	0.005615	31.52	0.0050	25.	0.0084	70.56
36	0.005000	25.00	0.0040	16.	0.0076	67.76
37	0.004453	19.83	...	....	0.0068	46.24
38	0.003965	15.72	...	....	0.0060	36.00
39	0.003531	12.47	...	....	0.0052	27.04
40	0.003145	9.888	...	....	0.0048	23.04

BROWN & SHARPE
TABLE OF DECIMAL EQUIVALENTS OF MILLIMETERS

Mm.	Inches	Mm.	Inches	Mm.	Inches	Mm.	Inches
.01 =	.00039	.33 =	.01299	.64 =	.02520	.95 =	.03740
.02 =	.00079	.34 =	.01339	.65 =	.02559	.96 =	.03780
.03 =	.00118	.35 =	.01378	.66 =	.02598	.97 =	.03819
.04 =	.00157	.36 =	.01417	.67 =	.02638	.98 =	.03858
.05 =	.00197	.37 =	.01457	.68 =	.02677	.99 =	.03898
.06 =	.00236	.38 =	.01496	.69 =	.02717	1 =	.03937
.07 =	.00276	.39 =	.01535	.70 =	.02756	2 =	.07874
.08 =	.00315	.40 =	.01575	.71 =	.02795	3 =	.11811
.09 =	.00354	.41 =	.01614	.72 =	.02835	4 =	.15748
.10 =	.00394	.42 =	.01654	.73 =	.02874	5 =	.19685
.11 =	.00433	.43 =	.01693	.74 =	.02913	6 =	.23622
.12 =	.00472	.44 =	.01732	.75 =	.02953	7 =	.27559
.13 =	.00512	.45 =	.01772	.76 =	.02992	8 =	.31496
.14 =	.00551	.46 =	.01811	.77 =	.03032	9 =	.35433
.15 =	.00591	.47 =	.01850	.78 =	.03071	10 =	.39370
.16 =	.00630	.48 =	.01890	.79 =	.03110	11 =	.43307
.17 =	.00669	.49 =	.01929	.80 =	.03150	12 =	.47244
.18 =	.00709	.50 =	.01969	.81 =	.03189	13 =	.51181
.19 =	.00748	.51 =	.02008	.82 =	.03228	14 =	.55118
.20 =	.00787	.52 =	.02047	.83 =	.03268	15 =	.59055
.21 =	.00827	.53 =	.02087	.84 =	.03307	16 =	.62992
.22 =	.00866	.54 =	.02126	.85 =	.03346	17 =	.66929
.23 =	.00906	.55 =	.02165	.86 =	.03386	18 =	.70866
.24 =	.00945	.56 =	.02205	.87 =	.03425	19 =	.74803
.25 =	.00984	.57 =	.02244	.88 =	.03465	20 =	.78740
.26 =	.01024	.58 =	.02283	.89 =	.03504	21 =	.82677
.27 =	.01063	.59 =	.02323	.90 =	.03543	22 =	.86614
.28 =	.01102	.60 =	.02362	.91 =	.03583	23 =	.90551
.29 =	.01142	.61 =	.02402	.92 =	.03622	24 =	.94488
.30 =	.01181	.62 =	.02441	.93 =	.03661	25 =	.98425
.31 =	.01220	.63 =	.02480	.94 =	.03701	26 =	1.02362
.32 =	.01260						

TABLE SHOWING RELATION OF WAVE LENGTH, FREQUENCY, AND THE PRODUCT OF INDUCTANCE AND CAPACITY

(U. S. Bureau of Standards.)

λ =Wave length in meters.

f =Frequency in kilocycles.

$\omega = 2\pi F$

CL=Micromicrofarads × inductance in centimeters.

(Note: To obtain capacity in microfarads in this table, multiply CL by .001.)

λ	*f*	ω	CL
1	300000	1884000	0.0003
2	150000	942000	.0011
3	100000	628000	.0018
4	75000	471000	.0045
5	60000	377000	.0057
6	50000	314200	.0101
7	42900	269000	.0138
8	37500	235500	.0180
9	33330	209400	.0228
10	30000	188400	.0282
15	20000	125600	.0635
20	15000	94200	.1129
25	12000	75400	.1755
30	10000	62800	.2530
35	8570	53800	.3446
40	7500	47100	.450
45	6670	41900	.570
50	6000	37700	.704
55	5450	34220	.852
60	5000	31420	1.014
65	4620	28970	1.188
70	4290	26900	1.378
75	4000	25120	1.583
80	3750	23520	1.801
85	3529	22120	2.034
90	3333	20920	2.280
95	3158	19830	2.541
100	3000	18840	2.816
105	2857	17940	3.105
110	2727	17130	3.404
115	2609	16380	3.721
120	2500	15710	4.05
125	2400	15070	4.40
130	2308	14480	4.76
135	2222	13950	5.13
140	2144	13450	5.52
145	2069	12980	5.92
150	2000	12560	6.34
155	1935	12150	6.76
160	1875	11770	7.20
165	1818	11410	7.66
170	1765	11080	8.13
175	1714	10760	8.62
180	1667	10470	9.12
185	1622	10180	9.63
190	1579	9910	10.16
195	1538	9660	10.71

λ	*f*	ω	CL
200	1500	9420	11.26
205	1463	9190	11.83
210	1429	8970	12.41
215	1395	8760	13.01
220	1364	8560	13.62
225	1333	8370	14.25
230	1304	8190	14.89
235	1277	8020	15.55
240	1250	7850	16.22
245	1225	7690	16.90
250	1200	7540	17.60
255	1177	7390	18.31
260	1154	7250	19.03
265	1132	7110	19.77
270	1111	6980	20.52
275	1091	6860	21.29
280	1071	6740	22.07
285	1053	6620	22.87
290	1035	6500	23.66
295	1017	6380	24.50
300	1000	6280	25.33
310	968	6080	27.05
320	938	5890	28.83
330	909	5700	30.66
340	882	5540	32.55
350	857	5380	34.48
360	833	5230	36.48
370	811	5090	38.54
380	790	4953	40.7
390	769	4830	42.8
400	750	4710	45.0
410	732	4590	47.3
420	714	4480	49.7
430	698	4380	52.0
440	682	4280	54.5
450	667	4190	57.0
460	652	4100	59.6
470	638	4010	62.3
480	625	3920	64.8
490	612	3842	67.6
500	600	3766	70.4
510	588	3692	73.3
520	577	3620	76.0
530	566	3552	79.0
540	556	3485	82.1
550	545	3422	85.2
560	536	3361	88.4

λ	*f*	ω	CL
570	526	3302	91.4
580	517	3246	94.7
590	509	3193	98.0
600	500	3140	101.4
610	492	3088	104.7
620	484	3038	108.2
630	476	2990	111.7
640	469	2942	115.4
650	462	2896	118.8
660	455	2852	122.5
670	448	2810	126.3
680	441	2768	130.2
690	435	2730	134.1
700	429	2692	137.8
710	423	2654	141.9
720	417	2616	145.9
730	411	2580	150.0
740	405	2544	154.0
750	400	2510	158.3
760	394.8	2476	162.6
770	389.6	2443	166.8
780	384.6	2412	171.4
790	379.8	2382	175.6
800	375.0	2353	180.1
810	370.4	2325	184.7
820	365.9	2297	189.3
830	361.4	2270	194.0
840	357.1	2242	198.5
850	352.9	2214	203.4
860	348.8	2188	208.2
870	344.8	2162	213.2
880	340.9	2138	217.9
890	337.1	2115	222.9
900	333.3	2092	228.0
910	329.7	2070	233.2
920	326.1	2047	238.1
930	322.6	2024	243.4
940	319.1	2003	248.7
950	315.8	1982	254.1
960	312.5	1962	259.5
970	309.3	1942	264.7
980	306.1	1922	270.4
990	303.0	1902	275.9

TABLE SHOWING RELATION OF WAVE LENGTH, FREQUENCY, AND THE PRODUCT OF INDUCTANCE AND CAPACITY—Continued.

λ	f	ω	CL	λ	f	ω	CL	λ	f	ω	CL
1000	300.0	1884	281.6	2000	150.0	942	1126	3000	100.0	628	2533
1050	285.7	1794	310.5	2050	146.3	920	1183	3500	85.7	538	3448
1100	272.7	1712	340.4	2100	142.9	898	1241	4000	75.0	471	4500
1150	260.9	1637	372.1	2150	139.5	876	1301	4500	66.7	418	5700
1200	250.0	1570	405	2200	136.4	856	1362	5000	60.0	377	7040
1250	240.0	1506	440	2250	133.3	838	1425	5500	54.5	342.2	8520
1300	230.8	1448	476	2300	130.4	819	1489	6000	50.0	314.2	10140
1350	222.2	1395	513	2350	127.7	801	1555	6500	46.2	289.8	11880
1400	214.4	1346	552	2400	125.0	784	1622	7000	42.9	268.8	13780
1450	206.9	1298	592	2450	122.5	768	1690	7500	40.0	251.0	15830
1500	200.0	1256	634	2500	120.0	753	1760	8000	3750	235.2	18010
1550	193.5	1215	676	2550	117.7	738	1831	8500	35.29	221.4	20340
1600	187.5	1177	720	2600	115.4	724	1903	9000	33.33	209.2	22800
1650	181.8	1142	766	2650	113.2	710	1977	10000	30.00	188.4	28160
1700	176.5	1108	813	2700	111.1	697	2052	15000	20.00	125.7	63400
1750	171.4	1076	862	2750	109.1	684	2129	20000	15.00	94.2	112600
1800	166.7	1046	912	2800	107.1	672	2207				
1850	162.2	1017	963	2850	105.3	660	2287	25000	12.00	75.4	176000
1900	157.9	990	1016	2900	103.5	648	2366	30000	10.00	62.8	253300
1950	153.8	965	1071	2950	101.7	638	2450	35000	8.57	53.8	344800
								40000	7.50	47.1	450000
								45000	6.67	41.8	570000
								50000	6.00	37.7	704000

DECIMAL EQUIVALENTS OF PARTS OF ONE INCH

1–64	.015625	17–64	.265625	33–64	.515625	49–64	.765625
1–32	.031250	9–32	.281250	17–32	.531250	25–32	.781250
3–64	.046875	19–64	.296875	35–64	.546875	51–64	.796875
1–16	.062500	5–16	.312500	9–16	.562500	13–16	.812500
5–64	.078125	21–64	.328125	37–64	.578125	53–64	.828125
3–32	.093750	11–32	.343750	19–32	.593750	27–32	.843750
7–64	.109375	23–64	.359375	39–64	.609375	55–64	.859375
1–8	.125000	3–8	.375000	5–8	.625000	7–8	.875000
9–64	.140625	25–64	.390625	41–64	.640625	57–64	.890625
5–32	.156250	13–32	.406250	21–32	.656250	29–32	.906250
11–64	.171875	27–64	.421875	43–64	.671875	59–64	.921875
3–16	.187500	7–16	.437500	11–16	.687500	15–16	.937500
13–64	.203125	29–64	.453125	45–64	.703125	61–64	.953125
7–32	.218750	15–32	.468750	23–32	.718750	31–32	.968750
15–64	.234375	31–64	.484375	47–64	.734375	63–64	.984375
1–4	.250000	1–2	.500000	3–4	.750000	1	1

TABLE FOR CONVERTING METERS TO KILOCYCLES OR VICE VERSA

(Note: By moving the decimal point the range of this table may be extended indefinitely.)

Kc	λm	Kc	λm	Kc	λm	Kc	λm
10....	29980	630....	475.9	1250....	239.9	1870....	160.3
20....	14990	640....	468.5	1260....	238.0	1880....	159.5
30....	9994	650....	461.3	1270....	236.1	1890....	158.6
40....	7496	660....	454.3	1280....	234.2	1900....	157.8
50....	5996	670....	447.5	1290....	232.4	1910....	157.0
60....	4997	680....	440.9	1300....	230.6	1920....	156.2
70....	4283	690....	434.5	1310....	228.9	1930....	155.3
80....	3748	700....	428.3	1320....	227.1	1940....	154.5
90....	3331	710....	422.3	1330....	225.4	1950....	153.8
100....	2998	720....	416.4	1340....	223.7	1960....	153.0
110....	2726	730....	410.7	1350....	222.1	1970....	152.2
120....	2499	740....	405.2	1360....	220.4	1980....	151.4
130....	2306	750....	399.8	1370....	218.8	1990....	150.7
140....	2142	760....	394.5	1380....	217.3	2000....	149.9
150....	1999	770....	389.4	1390....	215.7	2010....	149.2
160....	1874	780....	384.4	1400....	214.2	2020....	148.4
170....	1764	790....	379.5	1410....	212.6	2030....	147.7
180....	1666	800....	374.8	1420....	211.1	2040....	147.0
190....	1578	810....	370.2	1430....	209.7	2050....	146.3
200....	1499	820....	365.6	1440....	208.2	2060....	145.5
210....	1428	830....	361.2	1450....	206.8	2070....	144.8
220....	1363	840....	356.9	1460....	205.4	2080....	144.1
230....	1304	850....	352.7	1470....	204.0	2090....	143.5
240....	1249	860....	348.6	1480....	202.6	2100....	142.8
250....	1199	870....	344.6	1490....	201.2	2110....	142.1
260....	1153	880....	340.7	1500....	199.9	2120....	141.4
270....	1110	890....	336.9	1510....	198.6	2130....	140.8
280....	1071	900....	333.1	1520....	197.2	2140....	140.1
290....	1034	910....	329.5	1530....	196.0	2150....	139.5
300....	999.4	920....	325.9	1540....	194.7	2160....	138.8
310....	967.2	930....	322.4	1550....	193.4	2170....	138.1
320....	936.9	940....	319.0	1560....	192.2	2180....	137.5
330....	908.6	950....	315.6	1570....	191.0	2190....	136.9
340....	881.8	960....	312.3	1580....	189.8	2200....	136.3
350....	856.6	970....	309.1	1590....	188.6	2210....	135.7
360....	832.8	980....	305.9	1600....	187.4	2220....	135.1
370....	810.3	990....	302.8	1610....	186.2	2230....	134.4
380....	789.0	1000....	299.8	1620....	185.1	2240....	133.8
390....	768.8	1010....	296.9	1630....	183.9	2250....	133.3
400....	749.6	1020....	293.9	1640....	182.8	2260....	132.7
410....	731.3	1030....	291.1	1650....	181.7	2270....	132.1
420....	713.9	1040....	288.3	1660....	180.6	2280....	131.5
430....	697.3	1050....	285.5	1670....	179.5	2290....	130.9
440....	681.4	1060....	282.8	1680....	178.5	2300....	130.4
450....	666.3	1070....	280.2	1690....	177.4	2310....	129.8
460....	651.8	1080....	277.6	1700....	176.4	2320....	129.2
470....	637.9	1090....	275.1	1710....	175.3	2330....	128.7
480....	624.6	1100....	272.6	1720....	174.3	2340....	128.1
490....	611.9	1110....	270.1	1730....	173.3	2350....	127.6
500....	599.6	1120....	267.7	1740....	172.3	2360....	127.0
510....	587.9	1130....	265.3	1750....	171.3	2370....	126.5
520....	576.6	1140....	263.0	1760....	170.4	2380....	126.0
530....	565.7	1150....	260.7	1770....	169.4	2390....	125.4
540....	555.2	1160....	258.5	1780....	168.4	2400....	124.9
550....	545.1	1170....	256.3	1790....	167.5	2410....	124.4
560....	535.4	1180....	254.1	1800....	166.6	2420....	123.9
570....	526.0	1190....	252.0	1810....	165.6	2430....	123.4
580....	516.9	1200....	249.9	1820....	164.7	2440....	122.9
590....	508.2	1210....	247.8	1830....	163.8	2450....	122.4
600....	499.7	1220....	245.8	1840....	162.9	2460....	121.9
610....	491.5	1230....	243.8	1850....	162.1	2470....	121.4
620....	483.6	1240....	241.8	1860....	161.2	2480....	120.9

TABLE FOR CONVERTING METERS TO KILOCYCLES OR VICE VERSA—Continued.

Kc	λm	Kc	λm	Kc	λm	Kc	λm
2490....	120.4	3240....	92.54	4500....	66.63	6900....	43.45
2500....	119.9	3260....	91.97	4520....	66.33	6950....	43.14
2510....	119.5	3280....	91.41	4540....	66.04	7000....	42.83
2520....	119.0	3300....	90.86	4560....	65.75	7050....	42.53
2530....	118.5	3320....	90.31	4580....	65.46	7100....	42.23
2540....	118.0	3340....	89.77	4600....	65.18	7150....	41.93
2550....	117.6	3360....	89.23	4620....	64.90	7200....	41.64
2560....	117.1	3380....	88.70	4640....	64.62	7250....	41.35
2570....	116.7	3400....	88.18	4660....	64.34	7300....	41.07
2580....	116.2	3420....	87.67	4680....	64.06	7350....	40.79
2590....	115.8	3440....	87.16	4700....	63.79	7400....	40.52
2600....	115.3	3460....	86.65	4720....	63.52	7450....	40.24
2610....	114.9	3480....	86.16	4740....	63.25	7500....	39.98
2620....	114.4	3500....	85.66	4760....	62.99	7550....	39.71
2630....	114.0	3520....	85.18	4780....	62.72	7600....	39.45
2640....	113.6	3540....	84.70	4800....	62.46	7650....	39.19
2650....	113.1	3560....	84.22	4820....	62.20	7700....	38.94
2660....	112.7	3580....	83.75	4840....	61.95	7750....	38.69
2670....	112.3	3600....	83.28	4860....	61.69	7800....	38.44
2680....	111.9	3620....	82.82	4880....	61.44	7850....	38.19
2690....	111.5	3640....	82.37	4900....	61.19	7900....	37.95
2700....	111.0	3660....	81.92	4920....	60.94	7950....	37.71
2710....	110.6	3680....	81.47	4940....	60.69	8000....	37.48
2720....	110.2	3700....	81.03	4960....	60.45	8050....	37.25
2730....	109.8	3720....	80.60	4980....	60.20	8100....	37.02
2740....	109.4	3740....	80.17	5000....	59.96	8150....	36.79
2750....	109.0	3760....	79.74	5050....	59.37	8200....	36.56
2760....	108.6	3780....	79.32	5100....	58.79	8250....	36.34
2770....	108.2	3800....	78.90	5150....	58.22	8300....	36.12
2780....	107.8	3820....	78.49	5200....	57.66	8350....	35.91
2790....	107.5	3840....	78.08	5250....	57.11	8400....	35.69
2800....	107.1	3860....	77.67	5300....	56.75	8450....	35.48
2810....	106.7	3880....	77.27	5350....	56.04	8500....	35.27
2820....	106.3	3900....	76.88	5400....	55.52	8550....	35.07
2830....	105.9	3920....	76.49	5450....	55.01	8600....	34.86
2840....	105.6	3940....	76.10	5500....	54.51	8650....	34.66
2850....	105.2	3960....	75.71	5550....	54.02	8700....	34.46
2860....	104.8	3980....	75.33	5600....	53.54	8750....	34.27
2870....	104.5	4000....	74.96	5650....	53.07	8800....	34.07
2880....	104.1	4020....	74.58	5700....	52.60	8850....	33.88
2890....	103.7	4040....	74.21	5750....	52.14	8900....	33.69
2900....	103.4	4060....	73.85	5800....	51.69	8950....	33.50
2910....	103.0	4080....	73.49	5850....	51.25	9000....	33.31
2920....	102.7	4100....	73.13	5900....	50.82	9050....	33.13
2930....	102.3	4120....	72.77	5950....	50.39	9100....	32.95
2940....	102.0	4140....	72.42	6000....	49.97	9150....	32.77
2950....	101.6	4160....	72.07	6050....	49.56	9200....	32.59
2960....	101.3	4180....	71.73	6100....	49.15	9250....	32.41
2970....	100.9	4200....	71.39	6150....	48.75	9300....	32.24
2980....	100.6	4220....	71.05	6200....	48.36	9350....	32.07
2990....	100.3	4240....	70.71	6250....	47.97	9400....	31.90
3000....	99.94	4260....	70.38	6300....	47.59	9450....	31.73
3020....	99.28	4280....	70.05	6350....	47.22	9500....	31.56
3040....	98.62	4300....	69.73	6400....	46.85	9550....	31.39
3060....	97.98	4320....	69.40	6450....	46.48	9600....	31.23
3080....	97.34	4340....	69.08	6500....	46.13	9650....	31.07
3100....	96.72	4360....	68.77	6550....	45.77	9700....	30.91
3120....	96.10	4380....	68.45	6600....	45.43	9750....	30.75
3140....	95.48	4400....	68.14	6650....	45.09	9800....	30.59
3160....	94.88	4420....	67.83	6700....	44.75	9850....	30.44
3180....	94.28	4400....	67.53	6750....	44.42	9900....	30.28
3200....	93.69	4460....	67.22	6800....	55.09	9950....	30.13
3220....	93.11	4480....	66.91	6850....	43.77	10000....	29.98

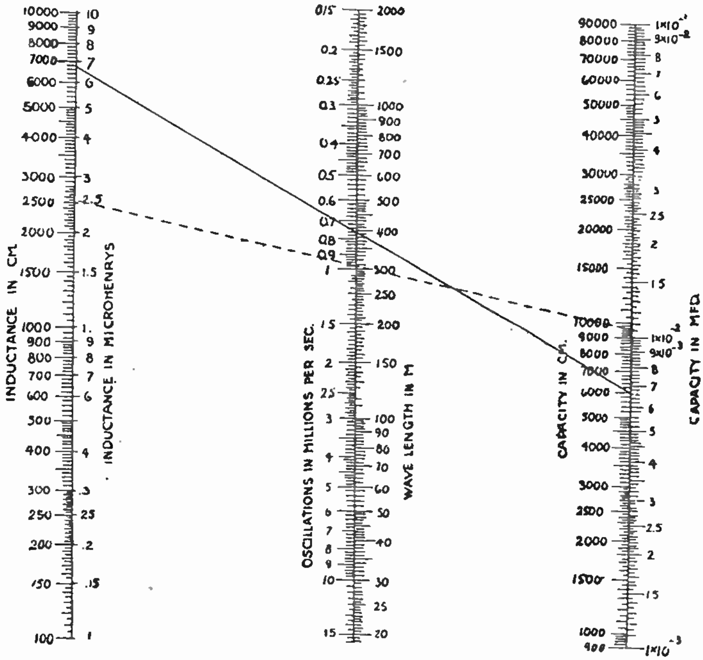


Chart for finding Wave Length of any Circuits Having Inductance and Capacity, whether Antenna Circuits or Laboratory Coils, without use of Formulas.

(From Popular Science Monthly, February, 1920.)

To use, merely lay a ruler across the chart so as to touch any two known values, and the desired unknown value will be shown at the point of intersection.

HONEY-COMB-COIL DATA

Number of Turns on Coil	Size of Wire B. & S. Guage	Inductance in Millihenrys	Distributed Capacity in Micromicrofarads	Natural Wave-Length in Meters	Wave-Lengths With the Following Shunt-Condenser Capacities Microfarads			
					.001	.0005	.00025	.0001
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

APPROXIMATE WAVE-LENGTHS OF 4-FOOT COIL ANTENNAE 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	7,500	9,000	15,650	20,500	27,200	32,900	10 turns per slot

TABLE OF WAVE LENGTHS ALLOTTED TO STATIONS

Kilocycles	Meters	Type of transmission	Service	Remarks
95–120	3,156–2,499	CW and ICW	Government only	
120–153	2,499–1,960	CW and ICW	Marine and aircraft only	
125	2,399	CW	Government	Nonexclusive
153–165	1,960–1,817	CW and ICW	Point to point, marine and aircraft only	
155	1,934	CW and ICW	Government	Do.
165–190	1,817–1,578	CW and ICW	Point to point and marine only	
175	1,713	CW and ICW	Government	Do.[1]
190–230	1,578–1,304	CW and ICW	Government only	
230–235	1,304–1,276	CW and ICW	University and college experimental only.	
235–285	1,276–1,052	Phone	Marine only	
245	1,224	CW and ICW	Government	Do.
275	1,090	CW and ICW	....do	Do.
285–500	1,052–600		Marine and coastal only	
300	1,000	CW and ICW	Beacons only	
315	952	CW and ICW	Government only	
343	874	CW and ICW	Marine only	
375	800	CW and ICW	Radio compass only	
410	731	CW, ICW, spark	Marine only	
425	706	CW, ICW, spark	....do	
445	674	CW and ICW	Government	Do.
454	660	CW, ICW, spark	Marine only	
500	600	CW, ICW, spark, phone	Calling and distress, and messages relating thereto, only.	
500–550	600–545	CW, ICW, phone	Aircraft and fixed safety of life stations.	Do.
550–1,500	545–200	Phone	Broadcasting only	
1,500–2,000	200–150	CW, ICW, phone	Amateur only	
2,000–2,250	150–133		Point to point	Do.
2,250–2,300	133–130		Aircraft only	
2,300–2,750	130–109		Mobile and Government mobile only	
2,750–2,850	109–105		Relay broadcasting only	
2,850–3,500	105–85.7		Public toll service, Government mobile, and point-to-point communication by electric power supply utilities, and point-to-point and multiple-address message service by press organization only.	
3,500–4,000	85.7–75.0		Amateur, Army mobile, naval aircraft, and naval vessels working aircraft, only.	
4,000–4,525	75.0–66.3		Public toll service, mobile, Government point to point, and point to point public utilities	Do.
4,525–5,000	66.3–60.0		Relay broadcasting only	
5,000–5,500	60.0–54.5		Public toll service only	
5,500–5,700	54.5–52.6		Relay broadcasting only	
5,700–7,000	52.6–42.8		Point to point only	
7,000–8,000	42.8–37.5		Amateur and Army mobile only	
8,000–9,050	37.5–33.1		Public toll service, mobile, Government point to point, and point-to-point public utilities	Do.
9,050–10,000	33.1–30.0		Relay broadcasting only	
10,000–11,000	30.0–27.3		Public toll service only	
11,000–11,400	27.3–26.3		Relay broadcasting only	
11,400–14,000	26.3–21.4		Public service, mobile, and Government point to point	Do.
14,000–16,000	21.4–18.7		Amateur only	
16,000–18,100	18.7–16.6		Public toll service, mobile, and Government point to point	Do.
18,100–56,000	16.6–5.35		Experimental	
56,000–64,000	5.35–4.69		Amateur	
64,000–400,000	4.69–0.7496		Experimental	
400,000–401,000	0.7496–0.7477		Amateur	

[1] Ice patrol, broadcast, etc.

"The committee recommends, provided it can be demonstrated to the satisfaction of the Department of Commerce, that no other wave band than 1,500 to 1,750 kilocycles (200 to 171 meters) can be used to provide satisfactory commercial radiotelephony between the Hawaiian Islands, that portion of the allocation to amateurs be assigned such commercial radiotelephony in the Hawaiian district only."

RADIOTRON AND RECTRON CHARACTERISTICS

GENERAL								DETECTION					AMPLIFICATION							
MODEL	USE	BASE	MAXIMUM OVERALL DIAMETER	MAXIMUM OVERALL HEIGHT	"A" BATTERY VOLTAGE (SUPPLY)	FILAMENT TERMINAL VOLTAGE	FILAMENT CURRENT (AMPERES)	DETECTOR GRID RETURN LEAD TO	GRID LEAK (MEGOHMS)	GRID CONDENSER (MFD)	DETECTOR "B" BATTERY VOLTAGE	DETECTOR PLATE CURRENT (MILLIAMPERES)	AMPLIFIER "B" BATTERY VOLTAGE	AMPLIFIER "C" BATTERY VOLTAGE	AMPLIFIER • PLATE CURRENT (MILLIAMPERES)	OUTPUT RESISTANCE • (OHMS)	MUTUAL CONDUCTANCE • (MICROMHOS)	VOLTAGE AMPLIFICATION FACTOR	MAXIMUM UNDISTORTED OUTPUT (MILLIWATTS)
DETECTORS AND AMPLIFIERS																				
RADIOTRON UX-201-A	Detector Amplifier	R C A Large Standard UX Base	$1\frac{13}{16}$"	$4\frac{11}{16}$"	6 Storage	5.0	.25	+F	2 to 9	.00025	45	1.5	135 90	9 $4\frac{1}{2}$	2.5 2	11,000 12,000	725 675	8 8	55 15
RADIOTRON UV-199	Detector Amplifier	UV-199 Base	$1\frac{5}{16}$"	$3\frac{1}{2}$"	Dry Cell $4\frac{1}{2}$ Storage 4	3.0	.06	+F	2 to 9	.00025	45	1	90	$4\frac{1}{2}$	2.5	16,500	380	6.25	7
RADIOTRON UX-199	Detector Amplifier	R C A Small Standard UX Base	$1\frac{3}{16}$"	$4\frac{1}{8}$"	Dry Cell $4\frac{1}{2}$ Storage 4	3.0	.06	+F	2 to 9	.00025	45	1	90	$4\frac{1}{2}$	2.5	16,500	380	6.25	7
RADIOTRON WD-11	Detector Amplifier	WD-11 Base	$1\frac{3}{16}$"	$4\frac{1}{8}$"	Dry Cell $1\frac{1}{2}$ Storage 2	1.1	.25	+F	3 to 5	.00025	$22\frac{1}{2}$ to 45	1.5	90	$4\frac{1}{2}$	2.5	15,000	400	6	7
RADIOTRON WX-12	Detector Amplifier	R C A Large Standard UX Base	$1\frac{7}{16}$"	$4\frac{11}{16}$"	Dry Cell $1\frac{1}{2}$ Storage 2	1.1	.25	+F	3 to 5	.00025	$22\frac{1}{2}$ to 45	1.5	90	$4\frac{1}{2}$	2.5	15,000	400	6	7
DETECTORS																				
RADIOTRON UX-200	Detector Only	R C A Large Standard UX Base	$1\frac{13}{16}$"	$4\frac{11}{16}$"	6 Storage	5.0	1.0	-F	$\frac{1}{8}$ to 2	.00025	$16\frac{1}{2}$ to $22\frac{1}{2}$	1	—	—	—	—	—	—	—
RADIOTRON UX-200-A	Detector Only	R C A Large Standard UX Base	$1\frac{13}{16}$"	$4\frac{11}{16}$"	6 Storage	5.0	.25	-F	2 to 3	.00025	45	1.5	—	—	—	—	—	—	—
POWER AMPLIFIERS																				
RADIOTRON UX-120	Power Amplifier Last Audio Stage Only	R C A Small Standard UX Base	$1\frac{3}{16}$"	$4\frac{1}{8}$"	Dry Cell $4\frac{1}{2}$ Storage 4	3.0	.125	—	—	—	—	—	135	$22\frac{1}{2}$	6.5	6,600	500	3.3	110
RADIOTRON UX-112	Power Amplifier	R C A Large Standard UX Base	$1\frac{13}{16}$"	$4\frac{11}{16}$"	6 Storage	5.0	.5	—	—	—	—	—	$157\frac{1}{2}$ 135 90	$10\frac{1}{2}$ 9 6	8 6 2.5	4800 5500 8800	1670 1435 890	8.0 7.9 7.9	195 120 40
RADIOTRON UX-171	Power Amplifier Last Audio Stage Only	R C A Large Standard UX Base	$1\frac{13}{16}$"	$4\frac{11}{16}$"	6 Storage	5.0	.5	—	—	—	—	—	180† 135† 90	$40\frac{1}{2}$ 27 $16\frac{1}{2}$	20 16 10	2000 2200 2500	1500 1360 1200	3.0 3.0 3.0	700 330 130
RADIOTRON UX-210	Power Amplifier Oscillator	R C A Large Standard UX Base	$2\frac{3}{16}$"	$5\frac{3}{8}$"	Transformer / Storage 8 8 8 6 6 6	7.5 7.5 7.5 6.0 6.0 6.0	1.25 1.25 1.25 1.1 1.1 1.1	—•	—	—	—	—	425† 350† 250† $157\frac{1}{2}$ 135 90	35 27 18 $10\frac{1}{2}$ 9 $4\frac{1}{2}$	22 18 12 6 4.5 3	5000 5100 5600 7400 8000 9700	1550 1500 1330 1020 940 775	7.7 7.6 7.5 7.5 7.5 7.5	1540 925 340 90 65 18

RECTIFIERS

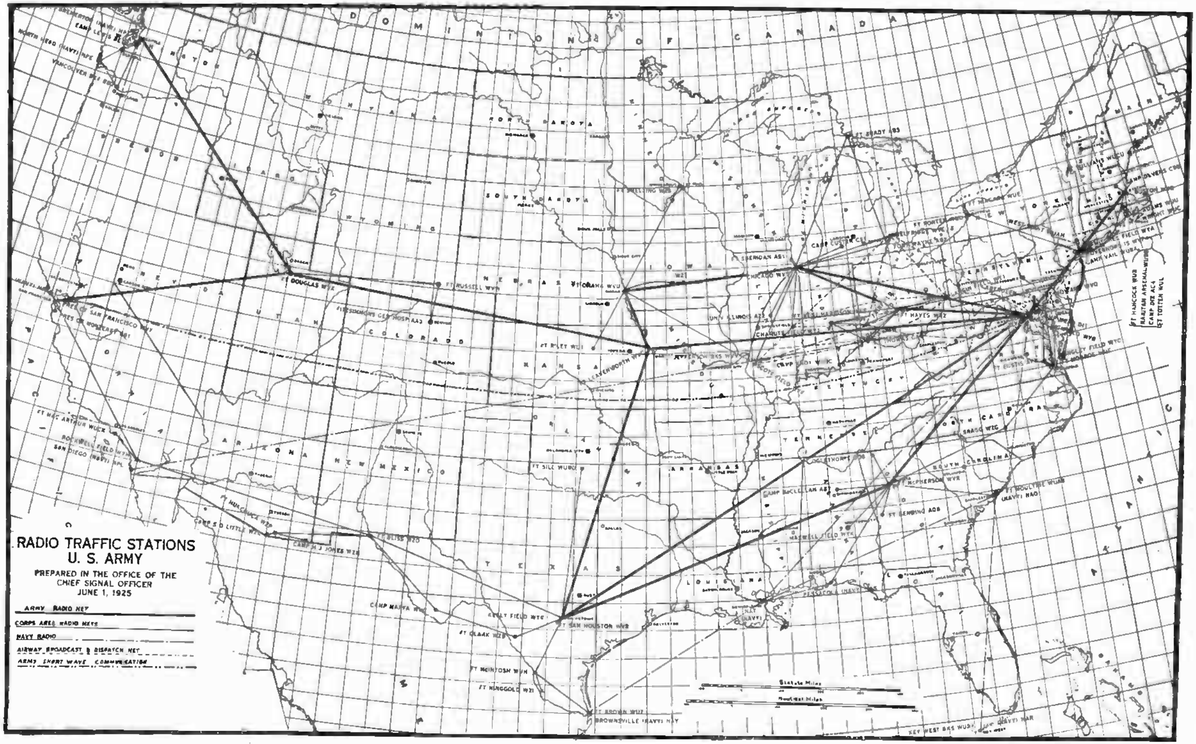
MODEL	USE	BASE	MAXIMUM OVERALL DIAMETER	MAXIMUM OVERALL HEIGHT	PURPOSE	
RECTRON UX-213	Full-Wave Rectifier	R C A Large Standard UX Base	$2\frac{3}{16}$"	$5\frac{5}{8}$"	For use in rectifying systems particularly designed for this Rectron.	Filament Terminal Voltage — 5.0 Volts Filament Current — 2.0 Amperes Max. AC Input Voltage per plate — 220 Volts (RMS) △ Max. Rectified Current (both plates) — 65 Milliamperes
RECTRON UX-216-B	Half-Wave Rectifier	R C A Large Standard UX Base	$2\frac{3}{16}$"	$5\frac{3}{8}$"	For use in rectifying systems particularly designed for this Rectron	Filament Terminal Voltage — 7.5 Volts Filament Current — 1.25 Amperes Max. AC Input Voltage — 550 Volts (RMS) △ Max. Rectified Current — 65 Milliamperes

SPECIAL PURPOSE RADIOTRONS

MODEL	USE	BASE	MAXIMUM OVERALL DIAMETER	MAXIMUM OVERALL HEIGHT	PURPOSE			
RADIOTRON UX-874	Voltage Regulator Tube	R C A Large Standard UX Base	$2\frac{3}{16}$"	$5\frac{3}{8}$"	Constant Voltage Device	Especially designed for use in the following devices operated from alternating current lighting mains:	R C A Duo-Rectron ("B" Battery Eliminator) R C A Loudspeaker Model 104	Voltage Drop — 90 Volts DC Starting Voltage — 125 Volts DC Maximum Current — 50 Milliamperes DC Positive (+) to Rod Negative (-) to Cylinder
RADIOTRON UV-876	Ballast Tube	Standard Mogul Type Screw Base	$2\frac{1}{16}$"	8"	Constant Current Device	Especially designed for use in the following devices operated from:- 105-125 Volts 50-75 Cycles	Radiola 30 R C A Loudspeaker Model 104 Brunswick Models PR-16C, -26C, 36C, 46C; PR 28C, -38C, 48C, P 3 Victor Models VV 15 1, VV 9 2, VV 12-2	Current Rating — 1.7 Amperes Voltage Drop — 40-60 Volts
RADIOTRON UV-886	Ballast Tube	Standard Mogul Type Screw Base	$2\frac{1}{16}$"	8"	Constant Current Device	Especially designed for use in the following devices operated from:- 105-125 Volts 40-45 Cycles	Radiola 30 R C A Loudspeaker Model 104 Brunswick Models PR-16C, 26C, 36C, 46C; PR-28C, 38C, 48C, P 3. Victor Models VV 15 1, VV 9 2, VV 12 2	Current Rating — 2.05 Amperes Voltage Drop — 40-60 Volts
RADIOTRON UV-877	Protective Tube	Double Contact Bayonet Automobile Type △△	$1\frac{7}{16}$"	$2\frac{1}{2}$"	Current Limiting Device	Used in "B" Battery circuits to prevent excessive current resulting from short-circuit which might damage tubes or wiring	Voltage Drop Across: Half Filament 2.5 / Entire Filament 5 — At 20 Milliamperes DC; Half Filament 45 / Entire Filament 90 — At 90 Milliamperes DC	

† Loudspeaker coupling recommended at this plate potential due to large plate current.
• At indicated "B" and "C" battery voltages

△ R M S indicates "Root Mean Square" as indicated on an AC voltmeter
△△ Connection to shell of base for third terminal which is the lead to mid point of filament



Map of U. S. Army Radio Net and Naval Stations.
(Naval Stations handle Navy and Public Commercial Traffic. Army Net is Strictly Government Work.)

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American Radio Journal, 116 West Thirty-ninth street, New York.
Experimental Wireless and the Wireless Engineer, The Watergate Press, 19 Surrey street, Strand, W. C. 2, London, England.
National Radio Review, 705 McGee street, Kansas City, Mo.
Popular Radio, 627 West Forty-third street, New York.
Popular Wireless, London, England.
Proceedings of the Institute of Radio Engineers, the College of the city of New York, 140th street and Convent avenue, New York.
QST, published by the American Radio Relay League, Inc., Hartford, Conn.
Radioelectricitie, 12 Place de Laborde, Paris.
Radio, published by the Pacific Radio Publishing Co., Pacific Building, San Francisco, Calif.
Radio Broadcast, Doubleday, Page & Co., 120 W. Twenty-third street, New York.
Radio Digest, 800 North Clark street, Chicago, Ill.
Radio Progress, 8 Temple street, Providence, R. I.
Radio Revista (Spanish), 4327 Guemes, Buenos Aires, Argentina.
Radio Life, 29 Temperance street, Toronto, Canada.
Radio Topics, 1112 North Boulevard, Oak Park, Ill.
Radio Journal, 113 Stimson Building, Los Angeles, Calif.
Radio World, 1493 Broadway, New York.
Radio News, the Experimenter Publishing Co., 53 Park Place, New York.
The Experimenter, Experimenter Publishing Co., 53 Park Place, New York.
Telegraph and Telephone Age, 253 Broadway, New York.
The Wireless Age, Wireless Press, 326 Broadway, New York.
Wireless World and Radio Review, 12 Henrietta street, London, England.

MAP

Rand McNally Radio Map of United States, Government, Broadcasting and Commercial Stations, with Call Letters and Wave Lengths. Rand McNally & Co., 536 S. Clark St., Chicago.. 35¢

OVER FOUR HUNDRED AND FIFTY REVIEW QUESTIONS

Elementary Principles

1. Describe a natural magnet; an artificial magnet; and explain the difference between a permanent and a temporary magnet.
2. State the law of magnetic attraction and repulsion.
3. On what does the permanency of magnets depend?
4. What substances are used for artificial magnets?
5. What is meant by magnetic permeability?
6. Give the right-hand rule for the direction of magnetic lines of force surrounding a charged wire.
7. What is an electromagnet?
8. Give a rule for determining the polarity of a solenoid.
9. What is meant by residual magnetism?
10. Define hysteresis.
11. What is a magnetic screen?
12. What is the difference between dynamic and static electricity?
13. Define a closed circuit; an open circuit; a divided circuit.
14. What is meant by a short-circuit, and what is its usual effect?
15. Explain the difference between direct and alternating current.
16. Name three methods of producing direct current.
17. Describe an insulator and name several examples.
18. Describe a conductor and name several examples.
19. Describe a simple chemical cell in detail.
20. What effect has increasing the size of the cell upon the output?
21. What is the effect of bringing the plates nearer together?
22. Define electrolysis.
23. Why are plates sometimes amalgamated?
24. What is the cause of polarization of a chemical cell? How may it be remedied?
25. What is meant by a difference of potential between the electrodes of a cell? Upon what does it depend?
26. Explain the electron theory of electric current and the direction of its flow. What constitutes a negative and a positive polarity?
27. Name several types of chemical cells and describe their characteristics.
28. What is meant by an open-circuit cell and a closed-circuit cell?
29. Give a diagram of cells in series, and of the same cells in parallel, and state their voltage and the available current in each connection.
30. Define a volt; an ampere; an ohm.
31. Give Ohm's law for direct current.
32. Define a watt; a kilowatt.
33. What is meant by Kva?
34. Give the rule for resistances in parallel, when their ohmic resistance is alike; when unlike.
35. Give the rule for like or unlike resistances in series.
36. Define a coulomb; a joule.
37. Define a foot-pound; a mechanical horsepower; an electrical horsepower.

38. Define an ampere hour.
39. Define a circular mil; a square mil.
40. Give the rule for finding the circular mil area of a round wire.
41. What is meant by the constant of a wire?
42. Does copper increase or decrease in resistance with heat?
43. Compare the hot resistance of tungsten and carbon filament lamps.
44. How would you determine the equivalent circular mil area of a square or rectangular conductor, and what would be the advantage of doing this?
45. What length and size of wire is used as a practical standard for one ohm in commercial electrical work?
46. Define induction; inductance.
47. Describe the process of induction in a simple transformer and name three types of transformers.
48. What is meant by the ratio of transformation?
49. Give a diagram of an induction-coil radio transmitter and explain its operation in detail.
50. Quote Lenz's law.

Alternators and Alternating Current

51. Explain the principle of operation of an alternator.
52. Explain the meaning of the sine curve when used to illustrate the output of an alternator.
53. Give the rule for determining the frequency of an alternator.
54. Explain the difference between a revolving-armature alternator and a revolving-field alternator.
55. What is the function of the collector rings on an alternator? Of slip rings?
56. Describe the construction and operation of an inductor alternator.
57. Give a diagram of a simple inductor-alternator radio transmitter.
58. Define pulsating current and describe a method of producing it.
59. What are the conditions necessary for producing alternating current?
60. What is meant by self-induction?
61. What is meant by the average value of alternating current? By the effective value?
62. Describe an alternating current 45 degrees out of phase.
63. Describe a two-phase alternating current.
64. Give diagrams of two different generator connections for producing three-phase current.
65. Quote the formula for determining the power of direct current; of alternating current out of phase.
66. What is meant by the skin effect of alternating current?
67. Define reactance; impedence.
68. What is meant by ampere turns?
69. Define a henry; a millihenry; a microhenry.
70. Explain what is meant by phase angle and power factor.
71. Name two effects of inductance in a circuit.

72. How can the reactive effect of inductance be overcome in a winding?
73. Give Ohm's law for alternating current, where inductive reactance only is present.
74. Give rules for finding inductance and impedence in a circuit.
75. Give formula for determining joint impedence of several impedence coils in series and in parallel.
76. Give rule for determining power factor.
77. Explain the reason for using alternating current for transmitting electric power over long lines.
78. Name two uses of inductance coils in connection with radio apparatus.

D. C. and A. C. Power Apparatus

79. How do an alternator and a direct-current generator differ?
80. Describe a commutator.
81. What is the function of the commutator in a d. c. generator?
82. Describe a shunt field self-excited generator.
83. What is the difference between no-load and full-load voltage of a generator?
84. Describe the arrangement of the rheostat in the shunt field, and the series field, of a self-excited d. c. generator, and explain the reason for each arrangement.
85. Describe a closed-coil and an open-coil-wound armature and effect of each type of winding.
86. Why are armature cores laminated?
87. What is the use of a rocker arm on a dynamo?
88. What is meant by the commutating plane? The neutral plane?
89. What is meant by distortion of dynamo flux?
90. How would you determine the efficiency of a d. c. generator?
91. How can an alternator have d. c. self-excited field windings?
92. Describe the construction and function of a fuse.
93. Describe the construction and operation of an overload or underload circuit breaker.
94. Give a wiring diagram of a simple shunt-wound dynamo and explain its operation as a d. c. generator or as a d. c. motor.
95. Give a wiring diagram of a series-wound dynamo and explain its operation as a d. c. generator or as a d. c. motor.
96. Give a wiring diagram of a compound-wound d. c. dynamo and explain its operation as a d. c. generator or as a d. c. motor.
97. What is the advantage of the compound winding over the simple shunt or series machine when used as a generator? As a motor?
98. What is the function of a commutator in a d. c. motor?
99. Name several causes of sparking at a commutator and remedies.
100. How would you increase the frequency of an alternator?
101. How would you increase the speed of a motor?
102. How would you increase the voltage of a shunt-wound d. c. generator?
103. What is the effect of cutting out resistance in the motor field rheostat? In the generator field rheostat?
104. What is the function of a motor starter?
105. Draw a diagram of a Cutler-Hammer hand-operated starting box, with three connections, hooked up to a differential com-

pound motor and a separately excited alternator. Draw the same for the General Electric starting box.

106. Is the resistance of the Cutler-Hammer hand starter, when connected with a motor which is running, operative or inoperative?
107. What is a no-voltage release magnet?
108. What causes a motor to "turn over"?
109. How can you determine the direction of rotation of a motor?
110. Upon what does the torque of a motor depend?
111. What are the effects of counter emf. in a motor?
112. What is Ohm's law for motors?
113. What causes a d. c. shunt motor to slacken its speed when a load is placed on it?
114. Explain the construction and effects of accumulative and differential motor windings.
115. What is the purpose of interpoles in a motor?
116. How can the magnetic field of a motor be regulated without a field rheostat?
117. What is the use of the characteristic curve of a motor?
118. Why is a series motor not desirable for operating a generator for purposes of radio communication?
119. How are motors rated commercially?
120. What determines the power of a motor?
121. Describe an induction motor.
122. What is a synchronous motor?
123. Describe the construction of a universal motor.
124. What is meant by the capacity of a motor and upon what does it depend?
125. What determines the amount of current that a d. c. motor will draw?
126. Why will a d. c. motor armature not be burned out upon allowing the full force of the power supply to be applied to it after the motor is going, if it will be burned out by allowing the full current of the line to go through it in the first place?
127. Describe the operation of a Marconi automatic starter.
128. Describe two methods of starting induction motors.
129. What is the function of the motor-generator in a radio transmitter?
130. Where are protective condensers usually placed in the power circuits of a radio transmitter? What are they used for?
131. Describe the construction and operation of a rotary converter; of a dynamotor.
132. Describe three types of transformers. Compare them.
133. Describe an auto-transformer.
134. What is the advantage of the shell-type transrormer?
135. Why are transformers sometimes immersed in oil?
136. What is the function of the step-up transformer in a spark transmitter?

Oscillating Current

137. What is a condenser? Name and describe several types.
138. Describe the oscillatory discharge of a condenser.
139. Upon what does the capacity of a condenser depend?
140. Define capacity.

141. Define a farad; a microfarad; a micromicrofarad.
142. What is meant by the constant of a dielectric?
143. Give rules for determining the capacity of condensers in parallel and in series.
144. Give reasons for the effects produced by connecting condensers in parallel or in series.
145. What is meant by free oscillations?
146. Define damping.
147. What is the function of the oscillation transformer in a radio transmitter?
148. What is meant by having the oscillation circuit in synchronism with the charging current?
149. What is meant by the radiation field, and upon what does it depend?
150. Why are high-frequency currents used for radio transmission?
151. Describe the effects of capacity in a series-resonant circuit.
152. Describe the effects of capacity and inductance in parallel with each other.
153. Why is a condenser sometimes placed in series with an a. c. power circuit?
154. What is meant by the resonant frequency?
155. Explain the difference between damped waves and continuous waves.
156. Explain the modern theory of the propagation of electric waves.
157. What is meant by interference and how can it be avoided?
158. Define a pure wave; a sharp wave.
159. Define a broad wave and explain causes of it. Why is it objectionable?
160. Define coupling and resonance between coupled circuits.
161. Explain the effects of close coupling and of loose coupling of a transmitter. What is meant by magnetic coupling?
162. What is meant by inductive coupling of a transmitter? Conductive? Capacitive? Draw a diagram of each type of coupling.
163. Draw a diagram of a plain aerial transmitter and explain its operation.
164. What is meant by the fundamental wave length of an antenna?
165. Explain two functions of a hot-wire ammeter in the antenna circuit of a transmitter.
166. Explain the function and operation of an added inductance coil in the antenna circuit.
167. Describe the construction and operation of a wavemeter used in determining the wave length of a transmitter.
168. What is a resonance curve and what is the object of making one?
169. What are the standard commercial wave lengths?
170. Give a simple formula for determining wave length when frequency is known; and one for frequency when wave length is known.
171. What determines the rate of damping in the closed circuit of a spark transmitter? In the open circuit?
172. What is meant by logarithmic decrement?
173. How is the logarithmic decrement determined?
174. Explain the construction and operation of a plain spark gap.
175. What is the effect of ionization at the spark gap?

176. What are the ideal conditions for a spark gap?
177. Describe the construction, operation and transmitting characteristics of a synchronous and non-synchronous rotary gap.
178. How can a rotary gap be synchronous when not adjusted to the alternator shaft?

Auxiliary Storage Batteries

179. Quote the law regarding auxiliary power supply.
180. Name three possible devices which could be used as auxiliaries in case of damage to a ship's dynamo.
181. Describe the construction of the Exide storage cell. What is its maximum voltage?
182. Describe the construction of the Edison cell. What is its maximum voltage?
183. What is meant by the specific gravity of electrolyte?
184. Compare the Exide and Edison cells.
185. Draw a fundamental diagram of a quenched-gap "spark" transmitter supplied with the storage-battery auxiliary power.

Receiving

186. Compare sound waves with electromagnetic waves used in radio communication.
187. Upon what does the pitch of a sound depend? The volume? The quality?
188. What is meant by the term audio frequency? Radio frequency?
189. Draw a diagram of, and describe the principle or operation of the standard telephone receiver.
190. Describe in detail how signals are transmitted between a telephone transmitter and receiver.
191. Upon what does the efficiency of a telephone receiver depend?
192. Explain the basis on which telephone receivers are given their commercial rating of resistance. About what is the usual resistance of a radiotelephone receiver? Of a landline telephone receiver?
193. Describe the mica-diaphragm telephone receiver.
194. Explain the function of a detector in a receiving circuit.
195. What is meant by the audio-frequency of a spark transmitter?
196. Upon what do the pitch, quality and loudness of the sounds heard in a radiotelephone receiver depend?
197. What is meant by the directional characteristics of an antenna?
198. What was the first receiving rectifier?
199. Name and describe several crystal detectors.
200. What are the advantages of a loose coupler in a receiving set?
201. Give a diagram and explain the operation of the simplest possible receiving set.
202. Draw a diagram of a conductively coupled receiving set employing a galena or silicon detector and explain the function of each part.
203. Draw a diagram of an inductively coupled receiving set using a carborundum detector and explain function of each part.
204. Draw diagrams showing three practical locations of a variable condenser in a receiving circuit; and explain effect of each.
205. What is the function of a loading coil in a receiver?

206. Draw a diagram of a capacitively coupled receiving set and explain its operation.
207. What is the function of an end turn switch and how is it constructed?
208. Explain fully the function of a buzzer tester. Draw diagrams showing three ways of connecting a buzzer tester to a receiving set and explain how you would construct a separate buzzer tester unit.
209. How does a potentiometer differ from a rheostat and when is one used in a crystal detector receiving apparatus?
210. What is the function of the telephone shunting condenser in a receiving set and what is its usual capacity?
211. Describe how you would install a receiving antenna, of what size and kind of wire you would make it; how you would predetermine its fundamental wave length and what kind of a ground you would use.
212. Explain the directional factor in a receiving antenna and how you would take advantage of this in installing an antenna with which you intend to communicate with some particular station.

Continuous Wave Transmitters

213. Describe in detail the construction and operation of the Alexanderson alternator, giving simple diagram of connections.
214. Upon what does the wave length of the Alexanderson alternator depend?
215. Describe a multiple-tuned antenna and explain the advantages and disadvantages of such an arrangement.
216. Describe the construction and explain the principle of operation of the Goldschmidt high-frequency alternator.
217. Describe the Marconi timed-spark transmitter.

Arc

218. Give a fundamental diagram of the arc transmitter.
219. Explain just how oscillations are produced by the arc transmitter.
220. Describe fully two different types of water-cooling systems used with the arc transmitter.
221. Upon what does the wave length of an arc transmitter depend?
222. Why are the arc electrodes enclosed in an airtight chamber?
223. How is hydrogen supplied to the arc? Why is it used?
224. What is the purpose of the exhaust from the arc chamber?
225. Why is the arc called a converter? How is it rated?
226. What is meant by blowout magnets? How do they have a double function?
227. Why is copper used for the positive electrode of the arc? How is it cooled?
228. Why is the carbon electrode of the arc transmitter revolved?
229. What is meant by the compensating-wave method of signaling and what are its disadvantages?
230. Give a diagram showing the use of an absorbing system of signaling with the arc transmitter.
231. Give a detailed diagram of the arc transmitter equipped with the back-shunt signaling system and explain its operation fully.

232. Describe two ways in which a chopper may be used with an arc transmitter. How does it affect the radiated waves?
233. Give a complete diagram showing the ignition-key system of arc signaling and explain its operation fully.
234. How are the arc magnets cooled?
235. What is meant by striking the arc?
236. Describe in detail how you would *start an arc transmitter into operation*, naming the consecutive order in which the various adjustments should be made.

Vacuum Tubes

(See questions 296 to 313.)

237. What is meant by the Edison effect in a vacuum tube?
238. Explain the electron theory of vacuum tubes.
239. What is meant by the saturation point of a vacuum tube?
240. Draw a diagram of a Fleming-valve receiving circuit and explain its operation.
241. What causes ionization of a vacuum tube and how can it be recognized? What are its advantages and disadvantages?
242. Explain why vacuum tubes are classified as hard and soft tubes and what each type is best suited for.
243. Why is the operation of a grid in a vacuum tube sometimes referred to as a "trigger action"?
244. Describe how various characteristic curves of a vacuum tube may be made and what is gained by them.
245. What is meant by the amplification coefficient of a tube?
246. What is meant by the constants of a tube?
247. Draw a fundamental diagram of a vacuum-tube receiver for damped waves.
248. Explain the effect of placing a condenser in series with the grid and the function of the grid leak.
249. Why is a vacuum tube sometimes called an electron relay?
250. What is the approximate range of plate current and voltage on which the average vacuum tube is operated in a simple receiving circuit? Filament current and voltage?
251. Why can non-interrupted continuous wave signals not be heard in the receiving telephones without some local modification?
252. Explain the meaning of heterodyne and draw a diagram of a two-tube vacuum-tube heterodyne receiver.
253. Draw a diagram of an autodyne receiver and explain its operation.
254. Draw a diagram of a single-circuit one-tube regenerative receiving circuit using variometer tuning and explain its operation.
255. Describe the ultra-audion receiving circuit and explain how it operates.
256. What is the fundamental principle of the super-regenerative circuit?
257. Is it possible to operate a vacuum-tube receiving set with filament current from an alternating-current city power line? How?

Vacuum-Tube Transmitters

258. How are power tubes used for transmitting rated? How are tube transmitters rated?
259. What would be the appropriate plate voltage and plate current to use with a 5-watt transmitting tube? With a 50-watt tube? With a 250-watt tube?
260. Why are power tubes sometimes water-cooled and how is this accomplished?
261. Describe the operation of a power tube in producing oscillations.
262. Draw a fundamental diagram of each of the following vacuum tube transmitting circuits, explaining the operation of each:
    (a) Tuned-grid-and-plate circuit.
    (b) Hartley circuit.
    (c) Colpitts' circuit.
    (d) Meissner circuit.
263. Describe a counterpoise and explain the reason for its use? How would you obtain a good ground on a rocky or sandy location?
264. What is the object of connecting several transmitting tubes in parallel?
265. Explain the master-oscillator system of vacuum-tube transmitting.
266. What effect has applying an alternating-current power supply directly on the plates of a vacuum-tube transmitter?
267. Describe an electrolytic rectifier and how to use such rectifiers in connection with vacuum-tube transmitters.
268. Describe three different types of direct-current plate supply for transmitting tubes.
269. Draw a full-wave self-rectifying vacuum-tube transmitter using a. c. for plate and filament.
270. Draw a diagram of a vacuum-tube transmitter having an a. c. filament supply and a kenotron-rectified plate supply.
271. Define modulation. What is meant by the carrier wave?
272. Describe an airplane installation of radio transmitter and receiver and how it differs from other installations.
273. Describe a short-wave tube transmitter, explaining how its extremely high frequency is produced.
274. Are transmitters using the self-rectifying system suited for radio-telephony? If not, why not?
275. How are the sounds of voice, music, etc., transmitted by a continuous-wave generating apparatus? Do the sounds travel?
276. Describe a carbon-granule microphone and its operation.
277. Describe the simplest possible method of radiotelephone transmission.
278. What is meant by the absorption method of radiotelephony?
279. Describe the Fessenden detuning method of radiotelephony.
280. Draw a diagram of a ferromagnetic modulating device and explain its operation.
281. Draw from memory a diagram of a one-tube vacuum-tube transmitter equipped for key transmission and radiotelephony with grid modulation.
282. Explain the action of the grid modulation on the plate current.
283. What are the advantages and disadvantages of grid modulation in radiotelephony?

284. Describe the modulation transformer used in radiotelephony.
285. Draw from memory a diagram of a radiotelephone circuit using the Heising system of modulation. Explain fully. Why is it called a constant-current system?
286. What are the advantages and disadvantages of Heising modulation?
287. What is the function of a grid-biasing battery in a radio-telephone transmitter? What is its usual voltage?
288. Describe several methods of employing buzzer modulation and the effect of this type of modulation.
289. Describe a method for checking on the modulation of a telephone transmitter. What methods are used for overcoming reverberations and echos in broadcasting studios?
290. Describe the single side-band method of radiotelephony and the type of receiving apparatus employed for its reception.
291. What is meant by multiplex radiotelephony?
292. Explain the principle of wired wireless.
293. What are the advantages of communication on extremely short wave lengths, such as 10 to 100 meters?
294. How are photographs transmitted by radio?
295. Describe how you would operate and care for a broadcasting station and explain why a licensed radiotelegraph operator is required in such a station.

Vacuum-Tube Receivers and Amplifiers

(See Questions 237 to 258)

296. Name three possible ways of amplifying intercepted signals.
297. Explain fully the difference between radio-frequency amplification and audio-frequency amplification. Compare a radio-frequency amplifying transformer with an iron core and without an iron core.
298. What is meant by cascade amplification? How many stages are usually practical?
299. How do the transformers used in audio-frequency amplifier circuits and radio-frequency circuits differ in construction?
300. Show by Ohm's law how you would determine the correct rheostat resistance to employ with a UV-199 tube; with a Cunningham 300 tube; with a UV-201-A tube; with two of each of these types of tubes connected in parallel.
301. Explain the function and location of a stablizer in radio-frequency amplifier.
302. Explain the working principles of a loud speaker.
303. How would you design a receiving set with which you desired to hear distant stations? Why?
304. How would you design a receiving set with which you intended only to listen to the local broadcasting stations? Why?
305. Describe three types of coupling which may be used between the different stages of an amplifier and compare their efficiency.
306. What are the advantages of jacks and plugs? Where are they used? Draw a diagram showing filament-lighting jacks connected in a receiving set.
307. Explain fully the principle of the super-heterodyne receiver and its advantages. Draw diagram.

308. What are the advantages and disadvantages of a loop antenna?
309. What is the principle of the neutrodyne receiver? Draw complete diagram of such a set.
310. Draw a diagram of a simple reflex receiving circuit and explain its operation.
311. What adaptations are being made of city power lines for radio? Explain their advantages and disadvantages.
312. Name the most common troubles in receivers, and their remedy.
313. Where is a C battery used in a radio receiver and what is its function?
314. How would you connect a soft-tube detector grid-terminal to the filament battery, and why? A hard tube?

The Practical Radio Operator

315. Draw a complete diagram of a modern spark-transmitter installation as used on seagoing vessels, including auxiliary source of power, and explain function of each part.
316. Draw a diagram of an auxiliary transmitter.
317. Draw a complete diagram of a vacuum-tube transmitter marine installation, with auxiliary power supply.
318. Draw a diagram showing how the type-1 antenna switch was used for protecting crystal-detector receivers.
319. Draw a diagram of an impact transmitter and explain its operation.
320. Name and describe four types of high-potential condensers used for transmitting.
321. What is the difference in results if the spark-gap of a spark transmitter is connected across the secondary terminals of the power transformer and the high-potential condensers in the usual location of the spark gap in commercial transmitters?
322. Draw a diagram showing an anchor spark-gap connected as it was used and explain its operation, advantages and disadvantages.
323. Draw diagrams of three receiving sets which can be used for receiving continuous-wave signals, making them audible on fundamentally different principles. Explain fully the operation of each.

Draw a diagram showing the fundamental principle of a stand-by receiver and explain its operation and advantages.

Draw a diagram of a receiver using an intermediate circuit and explain its advantage and disadvantage.

324. Describe the Rogers underground and underwater system of radio communication and explain its advantages and disadvantages.
325. How is automatic high-speed sending accomplished? What methods are used for the reception of high-speed sending?

Meters and Measurements

326. What is meant by a c.g.s. unit of measurement?
327. Describe the simplest type of galvanometer and its uses.
328. What is a tangent galvanometer?
329. Draw a diagram of a D'Arsenval ammeter; describe its construction, connection to the circuit and its operation.

330. Describe the connection and function of a calibrated shunt on an ammeter.
331. Draw a diagram of a D'Arsenval voltmeter and describe its construction, connection to the circuit and operation.
332. What is a voltmeter multiplier?
333. Draw a diagram of a dynamoter wattmeter and explain its operation.
334. What types of meters are most generally used for measuring quantity of current, voltage and power in alternating-current circuits?
335. What is an astatic meter?
336. Draw a diagram of a hot-wire ammeter and explain its operation.
337. Draw a diagram of a thermo-coupled ammeter and explain its construction and operation. Where is this type of meter most frequently used?
338. Draw a diagram of a reed frequency meter, explaining its operation.
339. Describe two other types of frequency meters.
340. Describe the construction and use of a power-factor meter.
341. Describe a kilowatt-hour meter and explain its operation in detail.
342. Draw a diagram of the Sangamo mercury ampere-hour meter and explain its operation. Where is this type of meter used in a majority of ship installations of radio apparatus?
343. Draw a diagram of a Wheatstone resistance bridge and explain its operation.
344. Describe the construction and uses of a megger.
345. Draw a diagram of a simple wavemeter and name nine uses for a wavemeter.
346. Describe how you would use a wavemeter in tuning a spark transmitter to a desired wave length.
347. What is a circuit-driver and what is it used for?
348. Draw a diagram of a Kolster decremeter and explain its uses and operation.
349. What is meant by a straight-line condenser?
350. Describe how you would use a wavemeter and an LC table for determining the capacity of an antenna circuit.
351. How would you use a wavemeter to measure the inductance of a coil?
352. What is the effect upon the wave length of coupling two resonant circuits together?
353. How would you measure the capacity of a condenser by means of a bridge?
354. How would you tune a receiving set to a calibrated wave length with a wavemeter?
355. How would you determine the wave length of a distant transmitter?
356. What methods are used for calibrating wavemeters?
357. Name the factors composing the antenna resistance.
358. Why must radiation resistance be high?
359. How would you go about measuring the radiation resistance of an antenna circuit?
360. Describe the nodal points in an antenna system.

361. How would you measure the constants of a vacuum tube?
362. Name several precautions to be observed in the use of meters.

Storage Batteries

(See Questions 179 to 185)

363. Describe how you would mix the electrolyte for a lead-acid cell.
364. What is the specific gravity of the Edison cell, and would you use a hydrometer reading of this in charging?
365. What is the normal temperature rating of storage batteries?
366. What would you do if taking batteries into extremely cold or hot climates?
367. Give rules for the care and upkeep of storage batteries and general precautions to be observed in their use.
368. What is the cause of sulphating in a lead cell and what treatment would you give a sulphated cell?
369. What causes the plates of a lead cell to buckle and how might you try to reclaim a buckled cell?
370. How would you prepare a bank of lead cells to be stored unused?
371. How would you prepare an Edison cell for storing?
372. How can you determine the polarity of a charging line?
373. Why can you not charge a storage battery directly from an alternating-current power line?
374. Draw diagrams and explain operation of three different types of rectifiers suitable for storage-battery charging.
375. What is meant by the watt-hour efficiency of a storage battery?

Installation and Care

376. Give general rules for installation of a ship station.
377. About what should the antenna ammeter reading of a 2-K. W. 500-cycle spark transmitter be when transmitting on a wave length of 600 meters? What is the capacity of the average ship's antenna? How would you obtain a suitable ground on board ship?
378. State rules and precautions for care and upkeep of a vacuum-tube transmitter.
379. How would you increase radiation with a quenched-spark gap? How does the effect of a quenched gap upon the radiated waves compare with the effect of a synchronous rotary gap? A non-synchronous gap?
380. Give general rules for the care of a ship station using spark set.
381. Give general rules for installation and care of arc transmitter.
382. Give rules for care of storage battery auxiliary.
383. Quote the essential points of the National Electric Code for the installation of radio transmitters.

Troubles

384. Describe in detail how and where you would trace the trouble in a spark transmitter when the spark failed to jump the gap.
385. What would you do in case you found an open in the field or armature coil of the motor-generator?

386. What would be the effect of an open in the shunt field of a compound-wound motor? A series field?
387. What would be the effect upon the generator output if there were an open in the field winding?
388. Does changing the voltage of the generator have any effect upon its frequency? Why?
389. Name several causes of sparking at the commutator of a d. c. dynamo and the remedy in each case.
390. What may cause overheating of the motor-generator and what is the effect?
391. What would you do with a motor-generator in which the shaft had "frozen"?
392. What would you do if the power transformer were damaged?
393. Name several causes of puncturing of condensers.
394. What would you do if one of a bank of condensers were damaged?
395. How would you carry on communication if all the condensers were ruined?
396. How would you keep up communication in case of irreparable damage to the motor-generator?
397. How would you perform your duties if the motor-generator and radio apparatus were all in working order but the ship's dynamo was out of commission?
398. How would you test a quenched gap for carbonized plates? How remedy?
399. What would you do to keep the motor-generator going if all of the starting resistance was burned out?
400. What is the effect of starting the motor too slowly? Too suddenly?
401. If the antenna ammeter gives no reading, what is indicated?
402. What would you do to determine radiation taking place if the antenna ammeter were burned out?
403. What would you do in case the antenna insulators were damaged beyond repair?
404. Name some causes of leaky antenna insulators. What is the effect? How test them?
405. What would you do if the masts on a ship were blown down and there were no poles for supporting your antenna?
406. Tell all that you can about the troubles likely to occur with an arc transmitter, and the remedies.
407. Name several safety precautions to be observed in handling an arc.
408. How would you test a receiving set for an open?
409. Name several possible causes for fluctuating signals.
410. How could you repair damaged telephone receivers?
411. Name some uses of a buzzer tester in locating troubles.
412. How could you determine if the plates of a variable condenser touch?
413. How would you protect a receiving set from lightning and excessive power induced into it from nearby high powered transmission?

Radio Compass

414. Explain the theory of operation of the radio-compass direction finder and tell what materials are necessary to conduct this work.
415. What is the difference between bilateral and unilateral direction finding?
416. What is meant by a ship's position?
417. What is a radio beacon?
418. If an operator at sea, how would you obtain the ship's position for the captain? Under what circumstances could he determine the position of the vessel with only one radio-compass bearing?
419. Describe the construction and operation of a sonic depth finder, and how you would use one in connection with radio-compass direction finding.
420. How would you call a shore station for obtaining radio-compass bearings? What wave length would you use?
421. How is radio-compass direction finding applicable to aviation?

Duties of the Practical Operator and Laws and Regulations

422. Describe exactly how and what you would transmit in order to establish communication with another ship.
423. Quote the most important points of the ship act of August 13, 1912.
424. What has been the most frequent cause for the revoking of commercial radio operators' licenses?
425. Name the penalties for the following offenses:
    (a) Sending a false distress call.
    (b) Sending other fraudulent message.
    (c) Willful interference.
    (d) Divulging the secrecy of a message.
    (e) Superfluous communication with other operators.
    (f) Operating a station without a license.
426. What are the commercial wave lengths allotted by the Department for regular message traffic?
427. What is the law regarding a pure wave?
428. What is the law regarding logarithmic decrement? Why?
429. What messages have precedence over all others?
430. What is the law regarding use of power in general? Within fifteen miles of a shore station? Within five miles of a shore station?
431. What is the United States law regarding auxiliary power? International law for same?
432. What is the rule regarding transmission of messages to nearest shore station? Has a customer the right to designate the routing of a message?
433. How would you, while at sea, ascertain the nearest shore station? Why would you locate it in this manner?
434. What is the international law regarding intercommunication between vessels of different systems?
435. What system is used in determining charges for radiograms? Explain it in detail.

436. Make a sample message form, including the body of the message, fill in the blanks and reckon the total charge for the message, sent directly to a shore station or relayed by another ship, or forwarded by land line.
437. Make out a sample abstract sheet, filling in the blanks for recording the above message in each case.
438. How would you determine the land-line forwarding rate if you did not know it and could not be sure of it from your rate sheet?
439. How would you determine the charges of a message in foreign money?
440. How would you request an acknowledgment of the receipt of a message and know that this has been complied with?
441. What does a radio operator put in his log?
442. To whom does a radio operator deliver his abstract sheet and cash?
443. Quote as many of the international abbreviation "Q" signals as you can. Interpret the signal PRB.
444. How many times may a radiogram be repeated and why?
445. Under what circumstances would you send an SOS call? State fully how you would proceed in calling for assistance. Who has authority to say that an SOS should be sent? How would you send an SOS with a vacuum-tube transmitter?
446. What would you do if, after sending out an SOS, the need for help no longer existed?
447. What would you do if, while listening in, you heard an SOS?
448. How would you treat a fellow-worker who had received an electric shock?
449. Name several safety precautions to be observed around radio apparatus.
450. How would you obtain medical help for a person taken ill on a vessel?

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