Modern Theory and Practice
in
Radio Communication

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A Text Book
Prepared for the Use of Midshipmen
at the United States Naval Academy

By

GORDON D. ROBINSON
M. E., M. S., S. M.

Associate Member
Institute of Radio Engineers

Assistant Professor, Department of
Electrical Engineering and Physics
U. S. Naval Academy

AND

PAUL L. HOLLAND
LIEUTENANT COMMANDER U. S. NAVY
Instructor, Department of
Electrical Engineering and Physics
U. S. Naval Academy

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PREFACE.

A need having arisen for the instruction of Midshipmen in Radio, beyond that previously provided, the authors have undertaken the production of a text suitable for that purpose.

Our endeavor has been to provide a book containing all the information necessary for the student who does not intend to specialize on Radio, and at the same time to produce a book which will serve as a basis for further study for the student who does wish to specialize. The book is not intended, however, for an instruction manual for a radio operator who has little interest in the how and why of his apparatus.

Requirements of time and space have made it necessary to take for granted various statements which would be derived mathematically, or explained in detail, in a text dealing purely with fundamentals. These omissions are of such a nature that they may profitably be studied only by a student specializing on radio subjects.

To understand the work as presented, the student should have a knowledge of elementary electricity and physics.

Credit is due Lieutenant Commander P. L. Holland for Chapters I, II, III, IV, VI and XII. The remaining chapters are to be credited to G. D. Robinson.

DEPARTMENT OF ELECTRICAL ENGINEERING
AND PHYSICS.
UNITED STATES NAVAL ACADEMY,
JULY, 1919.

LIST OF ABBREVIATIONS.

C—Capacitance.
E—Voltage or Potential.
E. M. F.—Electromotive force.
I—Current.
i—Instantaneous current.
L—Inductance.
M—Mutual inductance.
R—Resistance.
X—Reactance.
Z—Impedance.
f—Frequency in cycles per second.
ω—2 π times frequency.
mf.—microfarad.
mmf.—micromicrofarad.
mh.—millihenry.
μh—microhenry.
Q—Quantity of electricity.

CONTENTS.

MODERN THEORY AND PRACTICE IN RADIO COMMUNICATION.

CHAPTER I.

ELECTRON THEORY. ELECTRIC AND MAGNETIC STRAINS.

The phenomena of sound waves are familiar to the student of elementary physics. The production of disturbances in a medium as tangible as air, and the effects of the resulting waves, as sound, upon the human ear seem quite simple. Likewise light and heat waves, by whatever source produced, can be received or detected by our physical senses. These waves are the result of disturbances in a medium called ether, which pervades all space, and are somewhat analogous to water waves. In this medium can be produced waves of various lengths which manifest themselves in vastly different ways. Heat waves vary in length from 1/10000 to 1/100000 cm.; light waves from 36×10^{-6} to 80×10^{-6} cm. Shorter than any waves which we can detect as light are ultra-violet rays. These can be detected by their effect on chemicals or photographic plates. Still shorter are X-rays.

Waves in this medium, varying in length from approximately 100 meters to 20,000 meters are the means of conveying the energy in radio communication.

The problem of the radio engineer is the efficient production and reception of these extremely long ether waves.

In order that the student may more easily understand certain phenomena connected with radio, a slight digression is deemed necessary.

Electron Theory.

Modern science teaches that the atom, which is the smallest subdivision of matter with which the chemist has to deal, is in itself a very complex structure. Each atom is composed of a great many smaller particles, called electrons, which are in rapid orbital motion around a central portion or nucleus. These electrons have been proven to be charges of negative electricity, and the nucleus is conceived to be a positive charge of electricity. The experiments from which the electron theory has been evolved do more than prove the existence of electrons—the weight and size of each electron and the amount of negative charge carried by each has been computed to be as follows: mass, 8.8×10^{-28} gram; radius, 1×10^{-13} cm.; charge, 1.6×10^{-19} coulomb.

Following this conception of matter, the difference between atoms of different materials is a difference in number and arrangement and motion of electrons. In some atoms the arrangement seems to be stable, in others the motion of electrons is irregular, and some electrons are constantly leaving one atom and attaching themselves to some other atom. If the negative charges, or electrons, are held by the positive nucleus in a more or less stable arrangement the atom is neutral. If there are electrons in excess, or free electrons as they are called, attached to an atom, the atom is said to be negatively charged. If by any means the number of electrons is reduced below the number necessary for neutral state, the atom is positively charged. What is true of atoms is true of large bodies which are atoms taken collectively.

Under this theory we readily understand the charging by friction of bodies such as amber, rubber, fur, etc. Any body, when rubbed, has its molecular or atomic structure disturbed. If under this disturbance electrons detach themselves from atoms of one body and attach themselves to atoms of another body, the second body is negatively charged, and the first, with reduced number of electrons, is positively charged. Thus, the potentials of the two bodies are changed in the same degree, and for every positive charge induced there is an equal negative charge induced on another body. This condition is unstable—on one body are free electrons, on another there is a deficiency of electrons. If these two bodies are connected by a material through which the electrons can pass the free, or excess, electrons move from the negatively charged to the positively charged body, resulting in what is familiarly known to us as an electric current.

This tendency of electrons to move from the negatively charged to the positively charged body is manifested in what we are accustomed to call attraction between unlike charges. A material which can serve as a path for the electrons is called a conductor. The ease with which this transfer of electrons takes place is a measure of the conductance of the material. A good conductor offers very little resistance. An insulator, or dielectric, permits practically no passage of electrons. Recent research has led to the theory that this transfer of electrons through a conductor is not a continuous passage of numbers of electrons, like a current of air, but is a spontaneous movement from one atom to another, much like the effect noticed when the end ball in a bowling alley ball rack is struck a sharp blow. No apparent motion is noticed in the intermediate balls, but the ball at the far end moves off suddenly to a considerable distance.

That there is an attraction between two oppositely charged bodies and a repulsion between two bodies of like charge is proven by many simple experiments as outlined

FIG. 101.

in any text book on Electricity and Magnetism. Of more interest to radio students is the nature of the stress by means of which this pull or force is exerted. We know from our study of mechanics that there must be some medium under stress linking the two bodies in order that this force may be exerted. This medium is not air, as can be shown by performing the experiments in an exhausted chamber. Innumerable experiments convince us that this force is exerted by means of a strain in the ether. This condition of strain we represent by so-called lines of electric force. These lines are conceived as emanating from positive charges and terminating in negative charges of equal magnitude. Their direction is assumed to be that in which a positive charge if free would move. For simplicity we assume that at one end of each line is a free electron and at the other end is an atom from which an electron has been removed. There is a tendency of the lines to shorten themselves and at the same time a repulsion between lines in parallel directions which causes the curves as shown in Fig. 102. The cause of this repulsion is as yet

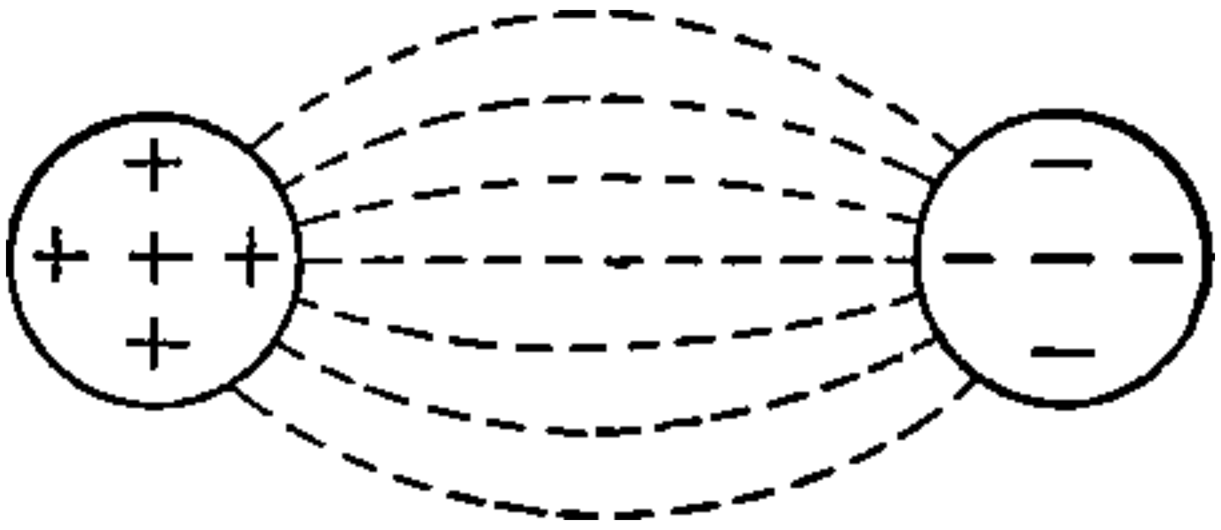


FIG. 102.—Electric Field Between Oppositely Charged Spheres.

unexplained. It may be due to arrangement of the molecules of the ether under strain.

The attraction which exists between a charged body and a neutral body is explained as follows. We have assumed that at the positive end of each strain line there is an atom which has been robbed of one or more electrons, and at the negative end is a free electron. If such electrons exist at the ends of the strain lines on the neutral body they must have been taken from the atoms of that body. As long as these electrons are held on the side of the neutral body nearest to the charged body, there must exist on the other side of the neutral body atoms from which electrons have been removed, or positively charged atoms. The effect is the same as though a positive charge had flowed to this side. The negative charge on the near side of the neutral body is called an induced charge.

FIG. 103.—Induced Charge.

Magnetic Lines of Force.

There is another form of strain set up in ether which is called magnetic strain, and represented by lines of magnetic force. This strain exists in the vicinity of an ordinary bar magnet, a piece of iron surrounded by a coil of wire carrying current, which is temporarily given the properties of a magnet, also around any wire carrying current. The direction of these lines can readily be shown by sprinkling iron filings on a piece of paper placed in the field of the lines.

For a more complete treatise on magnetic lines the student is referred to any text-book on Magnetism. The point of interest here is the existence of these strains—electric and magnetic—and the fact that the strains are

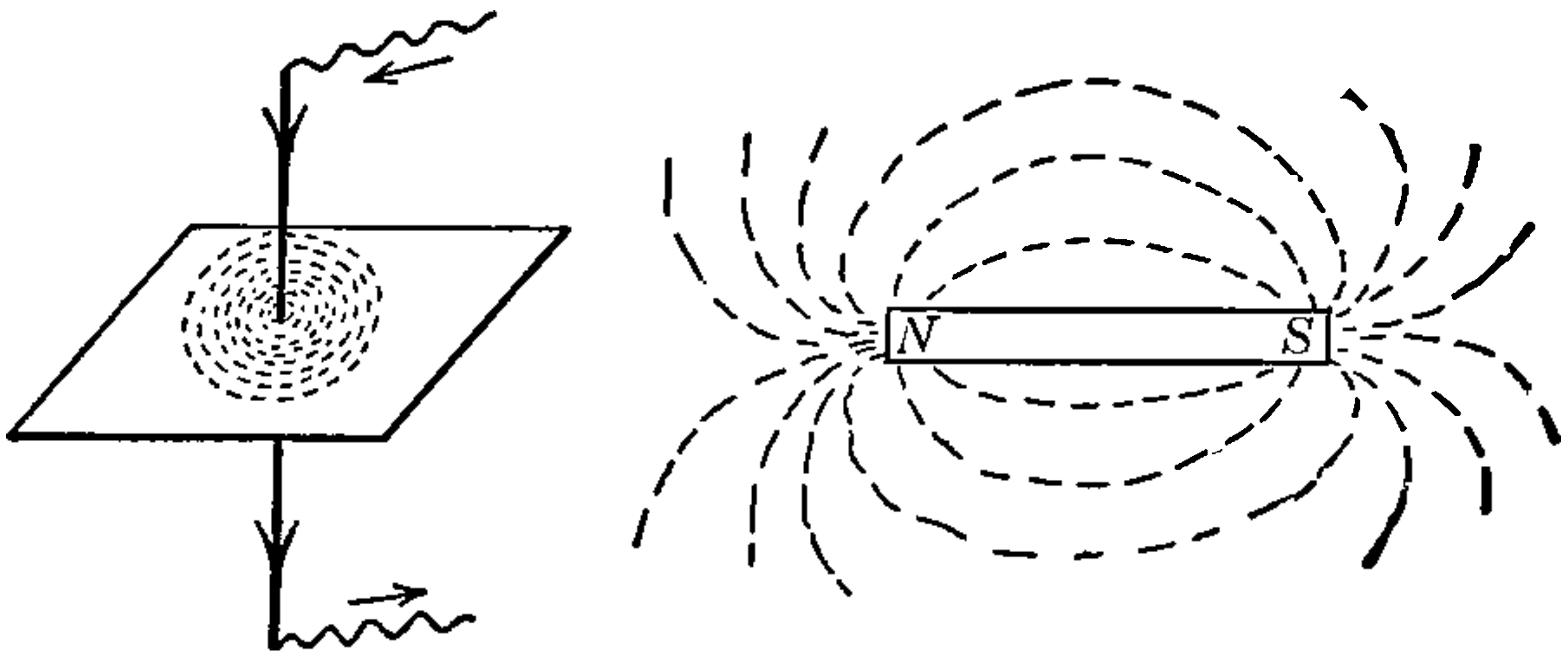
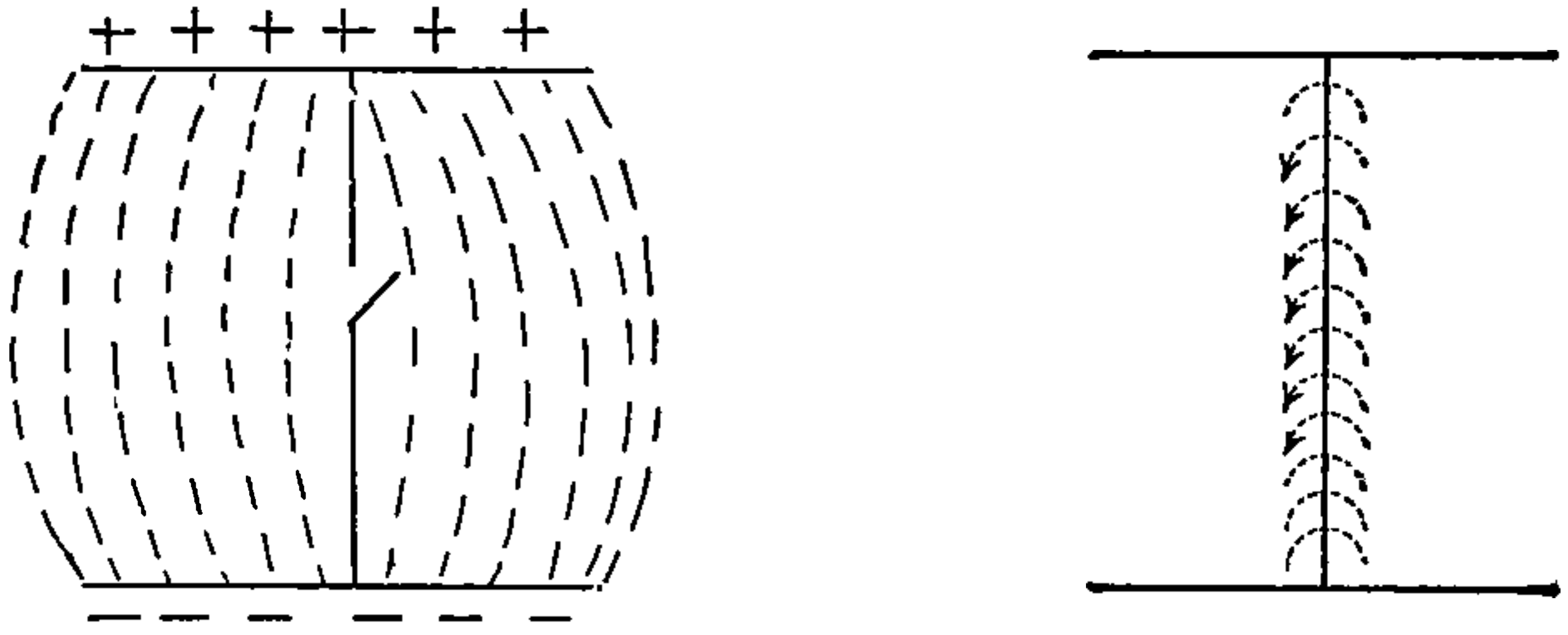


FIG. 104.—Magnetic Fields.

set up at right angles to each other. This is made clear by reference to Fig. 105. Suppose positive and negative charges to exist as shown. As long as these charges exist



Electric Strain. Magnetic Strain.

FIG. 105.—Electric Strain.

electric lines of force exist in the space between the plates. When the switch is closed there is a flow of current and a magnetic field is set up around the conductor joining the plates. The electric field is at its maximum before the switch is closed, and the magnetic field reaches its maximum approximately when the electric field is at its minimum, or when no potential difference exists between the plates. These fields may co-exist, temporarily, at less than maximum strength, one increasing and the other decreasing.

This phenomenon is of supreme importance in the propagation of electric waves from an antenna as will be explained later.

Energy of Strain.

In order that a spring or a piece of rubber may be put in a state of compression, or strain, work must be done on it. If the compressed spring is released it returns to its original form, and the force of the spring acting through a certain distance represents work. The work done by the spring in returning to its original form is equal to the work done in compressing the spring. The spring in its compressed state possesses potential energy by virtue of its strained condition. A strain in any medium or elastic body represents potential energy. The strains in the ether which we have just studied represent potential energy. Work must be done, by friction or otherwise, to charge a body. The equivalent of this work, in potential energy, is represented by the strain in the surrounding ether. Numerical expressions for this energy of strain will be given under the heading of condensers.

CHAPTER II.

CAPACITANCE AND INDUCTANCE. ENERGY OF CHARGES. CONDENSERS.

A thorough understanding of the underlying principles of capacitive and inductive effects is necessary before the student can progress in the study of radio telegraphy.

Capacitance.

We have already seen that a body can be charged, negatively or positively, and that there is an electric field surrounding such a body. The question arises, "How much charge can be put on a body of a given size?" The amount of gas we can put in a gas tank depends upon the size of the tank and upon the pressure of gas in the tank. Likewise, the quantity of electricity that can be placed on a body depends upon the size, or electrical capacity, and upon the electric pressure or potential. (We shall see later that the physical size of a body is not an absolute measure of its electrical capacity.) The quantity of gas in the tank is proportional to the cubical capacity of the tank times the pressure. The quantity of electricity is equal to capacity times potential. The capacity of a tank is fixed and is measured by the product of its linear dimensions. As we shall see, the electrical capacity of a body is determined not only by its size but by its proximity to other bodies and by the nature of the medium surrounding it.

Suppose we charge a body by connecting it to a source of E. M. F., then remove the connection to the source. A certain charge remains on the body. The quantity of

two bodies. If the two bodies are flat plates the field is as shown in Fig. 202. This concentration of the field into a small portion of the immediate surrounding medium increases the capacity.

The effect of the dielectric is to still further increase the number of lines in the intervening space. This also increases the capacity. This increase varies with the material used as a dielectric. The ratio of the capacity with the dielectric in use to the capacity with air between the bodies is called the specific inductive capacity, or dielectric constant of the material.

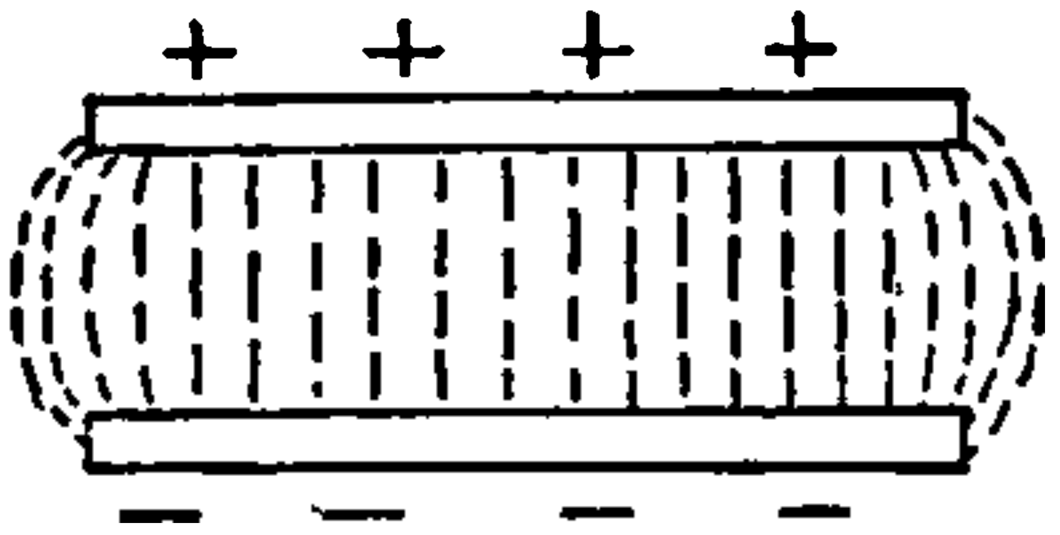


FIG. 202.—Distribution of Lines of Force Between Oppositely Charged Plates, or Between Charged and Neutral Plates.

The increase of strain lines takes place in the ether but is accompanied by a mechanical strain in the dielectric.

The unit of capacity is the Farad. This represents the capacity of a body which is charged to a potential of one volt by one coulomb of electricity. As this unit is large for practical purposes we use a unit one-millionth as large, called the microfarad.

Condensers.

A condenser is an arrangement of conductors and insulators to store up charges of electricity. In its usual form it consists of a number of metal plates separated by glass, oil, mica, air, paper, or some other insulator. In most of the condensers used in receiving in radio work the dielectric is air. By arranging two sets of plates, one set sliding into the space between the plates of the other set, both surfaces of all plates, except the outside ones, are made effective. Fig. 203 shows a condenser of this type.

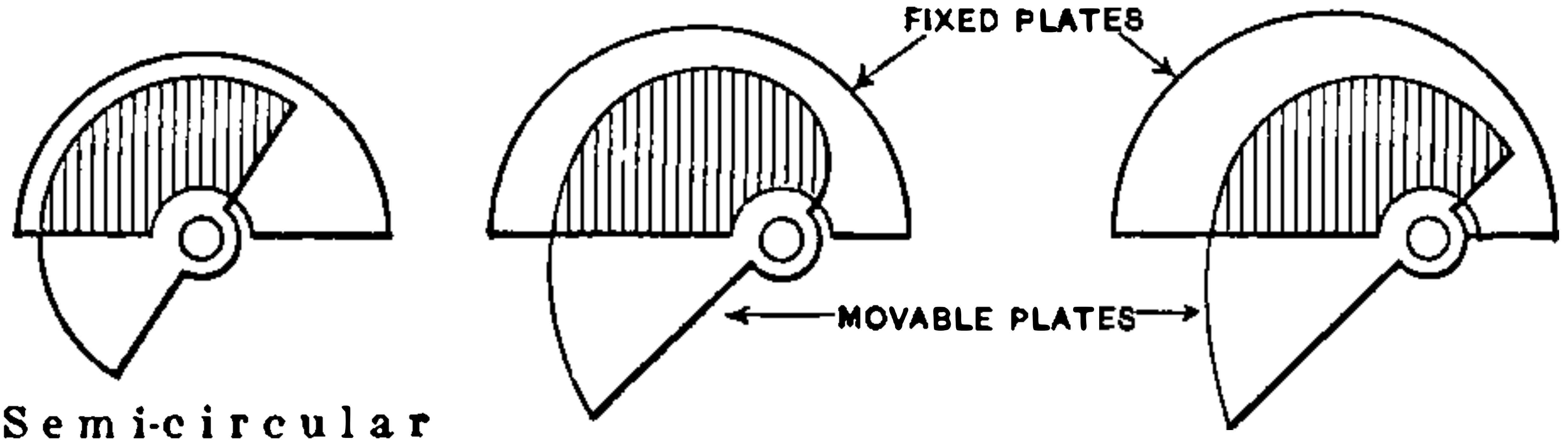
Various arrangements and shapes of plates are used. In the type most used in radio work the plates are so mounted that one set revolves with reference to the other set, thus varying the effective area of plates. The shape may be so designed that the effective area, hence capacity, varies as the angular displacement, or as the square of the angular displacement. The capacity of any plate condenser is found by the equation

FIG. 203.—**Sliding Plate Condenser.**

$$C,\text{ in mf.}=\frac{\text{Area of plates in cm.}^2\times\text{dielectric constant}}{4\times 3.1416\times 900000\times\begin{array}{c}\text{distance in cm.}\\ \text{between plates.}\end{array}}.$$

From this equation it is readily seen that by properly designing the shape of the plates the capacity can be made any function of the angular displacement between sets of plates. A few shapes in common use in radio work are shown in Fig. 204. Fixed capacity condensers are made up in various shapes and of quite large capacity.

The student can readily see from the foregoing that there must exist, between any two conductors near each other, a certain amount of electrostatic capacity. The amount depends upon the effective area of the conductors and the distance apart. In the case of a coil of wire of many turns and spaced close together this capacitance may be appreciable. The effective capacitance of a coil is a capacitance of such size that it will have the same amount of energy stored in it that is stored in the dielectric surrounding the coil, if equal A. C. voltages are applied to each. The amount of energy stored in the dielectric around the coil is, of course, a summation of $1/2\ CE^2$ (see "Energy of Charge in Condenser," page 26) where C is the capacitance between various parts of the coil and E is the voltage applied to that capacitance. It is convenient to consider the partial capacitances of the coil under two headings. First the capacitance between mechanically adjacent turns. Second the capacitance between turns which are not mechanically adjacent. In the case of any coil the capacitance between mechanically adjacent turns is larger than the capacitance between one turn and any other turn; but it does not at all follow that the energy stored in the dielectric of the coil is stored principally between adjacent turns. This may be seen by considering that as a rough approximation the voltage applied to the whole coil is divided equally between all the turns of the coil, and that



Capacity varies as square of angular displacement.

Kolster type.

Semi-circular plates. Capacity varies as angular displacement.

Percentage change per division is constant.

FIG. 204.

$W = 1/2\ CE^2$. Now if we compare two adjacent turns in a single layer solenoid with two turns separated, say, by nine turns, in the first case $W_1 = 1/2\ C_1E_1^2$, and in the second case $W_1 = 1/2\ C_{10}E_{10}^2$. C_{10} is nearly half of C_1.*

On the above assumed case it is seen that $E_{10}^2 = 100\ E_1^2$, while C_{10} is about half of C_1. The result is that the energy stored in the dielectric between adjacent wires is only about 2 per cent of that between the wires separated by nine turns. It is seen from this that in a single layer solenoid the effective capacitance is due principally to the capacitance of wires which are separated from each other by some distance. The stresses produced in the dielectric by the voltages between the various turns must be similar to Fig. 204A. This shows that displacement currents flow principally from the neighborhood of one end of the coil to

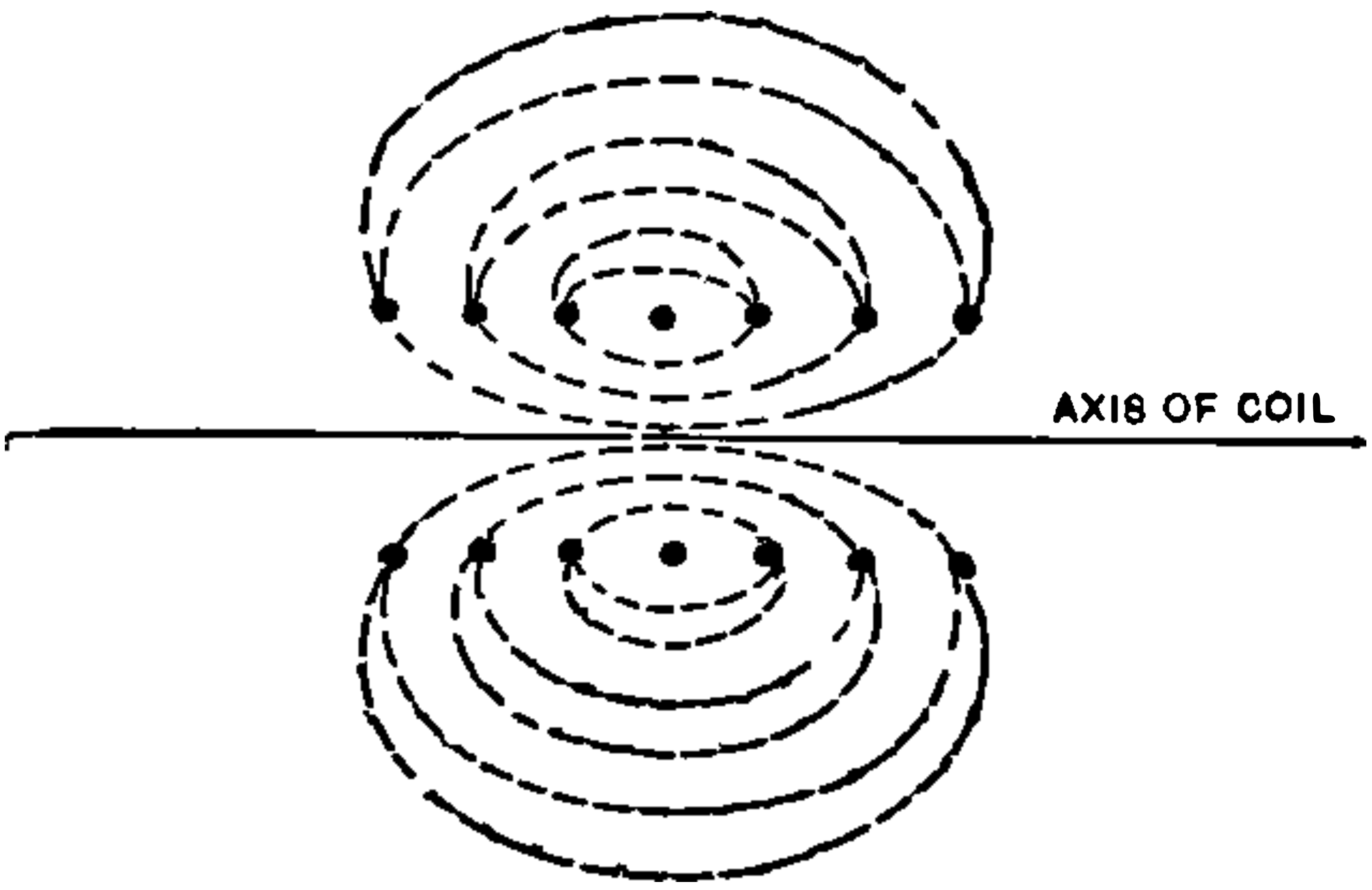


FIG. 204A.

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* See A. E. Kennelly, The Application of Hyperbolic Functions to Electrical Engineering Problems, p. 210, Fig. 87. The spacing between the copper of the wires has been estimated, in the case of double cotton covered wires of moderate size, as about 30 per cent of the diameter of the wire, and the capacitance taken from the above curves, which apply strictly only to straight wires.

the neighborhood of the other end. This occurs regardless of the number of turns in the coil (as long as turns are distributed along the entire length of the coil) so that the number of turns and the spacing between turns have relatively small effect on the effective capacitance of a single layer coil of given mechanical dimensions. The capacitance in this case, however, does vary approximately as the circumference of the turns.

If a multilayer coil is wound in the simplest manner, that is, with one layer directly over the preceding one, the ends of the two layers will come adjacent to each other; and if there are only a few layers, the voltage between these adjacent turns will be a large fraction of the whole voltage, and the effective capacitance of the coil will be large. The effective capacitance of a multilayer coil may be made relatively small in either one of two general ways. One is to have a large number of layers so that the voltage between adjacent layers is only a small part of the total. Coils of the approximate proportions of Fig. 204B are used in some types of radio apparatus. The second way of reducing the effective capacitance of a multilayer coil makes use of a special order of winding which puts mechanically adjacent turns only a few turns, electrically, from each other. The order of turns for a two-layer and for a four-layer winding is indicated in Fig. 204C. These are known

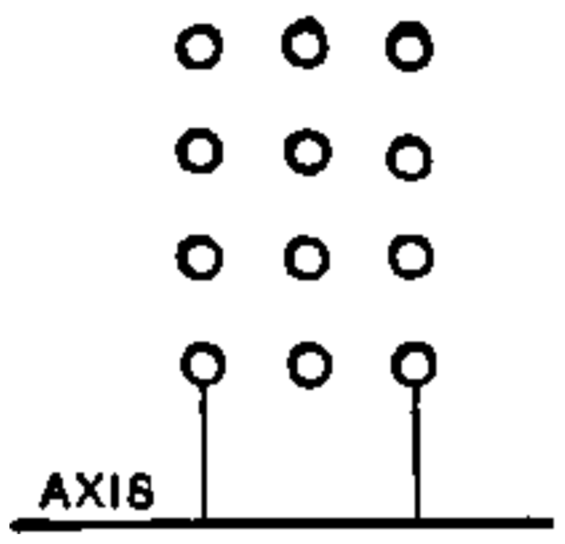

FIG. 204B.

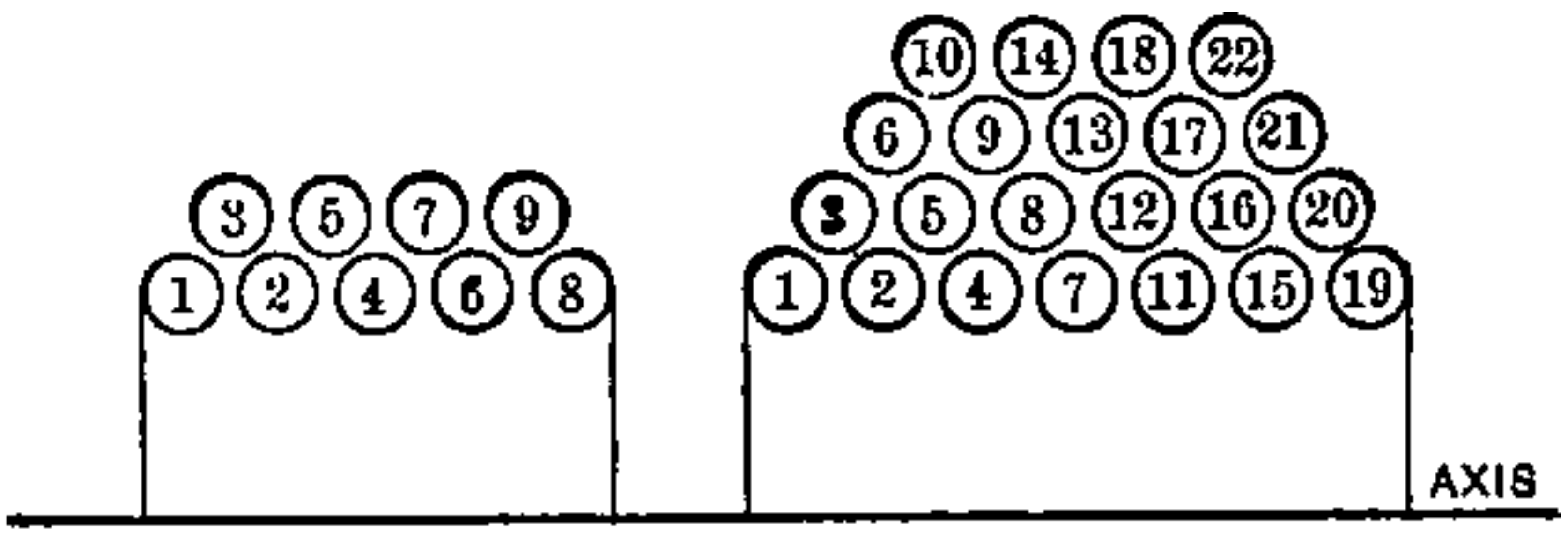

FIG. 204C.

as "banked windings." It is seen from the preceding that in a single layer coil the effective capacitance is due principally to the electrostatic capacity between turns which are not adjacent, while in a multilayer coil the effective capacitance is due principally to the electrostatic capacity between turns which are mechanically adjacent.*

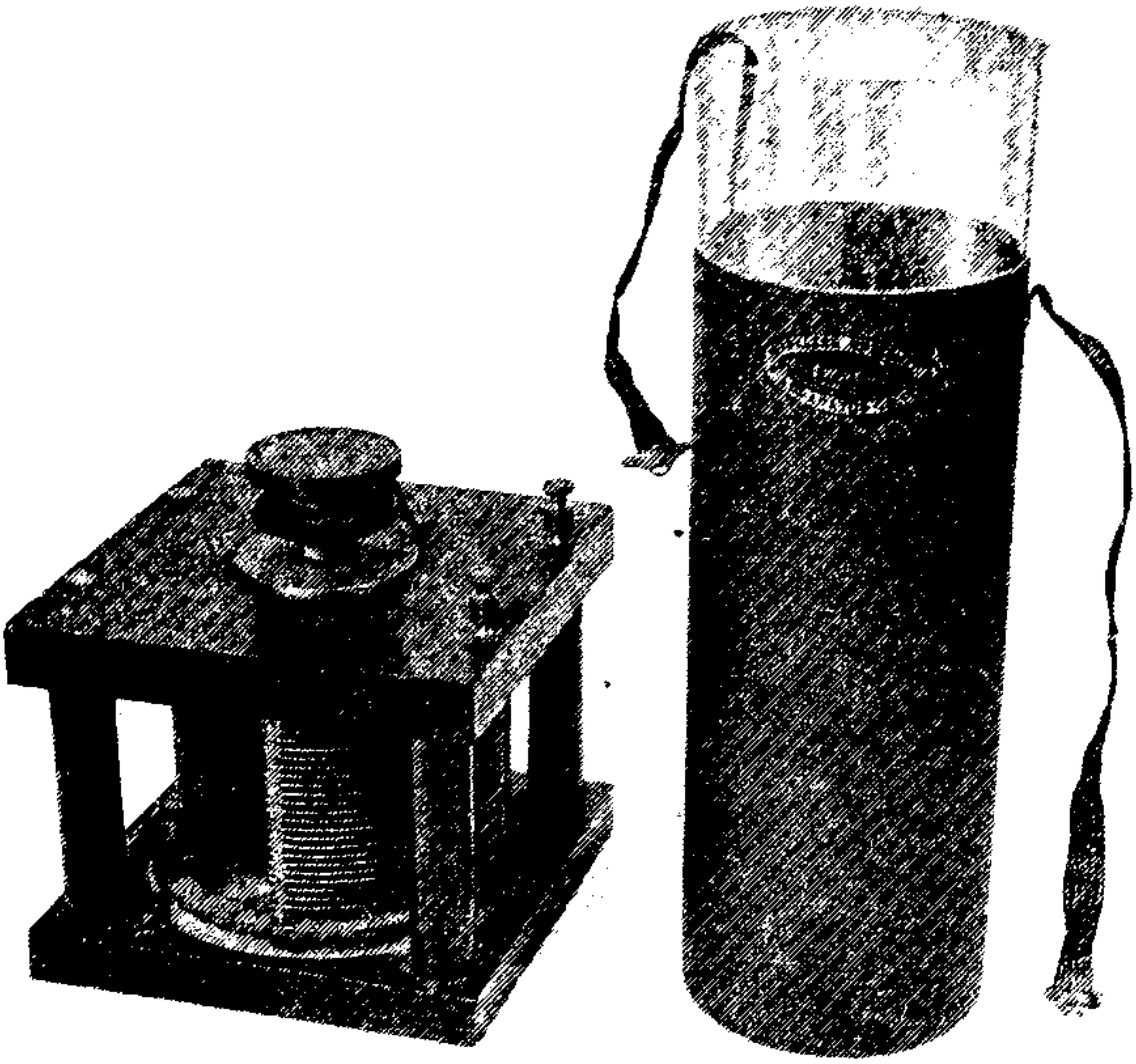

FIG. 204D.—Variable Air Condenser Semicircular Plates. Leyden Jar.

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* It should be seen from the preceding that where it is desired to reduce the effective capacitance of a coil system, it is much more important to reduce the fraction of the total voltage applied to the coil which appears between mechanically adjacent turns or parts, than to reduce the electrostatic capacity between those parts.

The effective capacitance is equivalent to a condenser connected across the terminals of the coil. There is also some capacitance between the coil and ground and from the coil to adjacent conductors. This capacity effect makes itself felt in radio compass work where a coil has some tendency to act as a simple antenna, also in the unipolar detector connections mentioned elsewhere.

Current Flow in Condenser Circuits.

Before going further let us study the flow of current into and out of a condenser. The most nearly correct analogy of an electric current is the flow of water in a system of pipes.

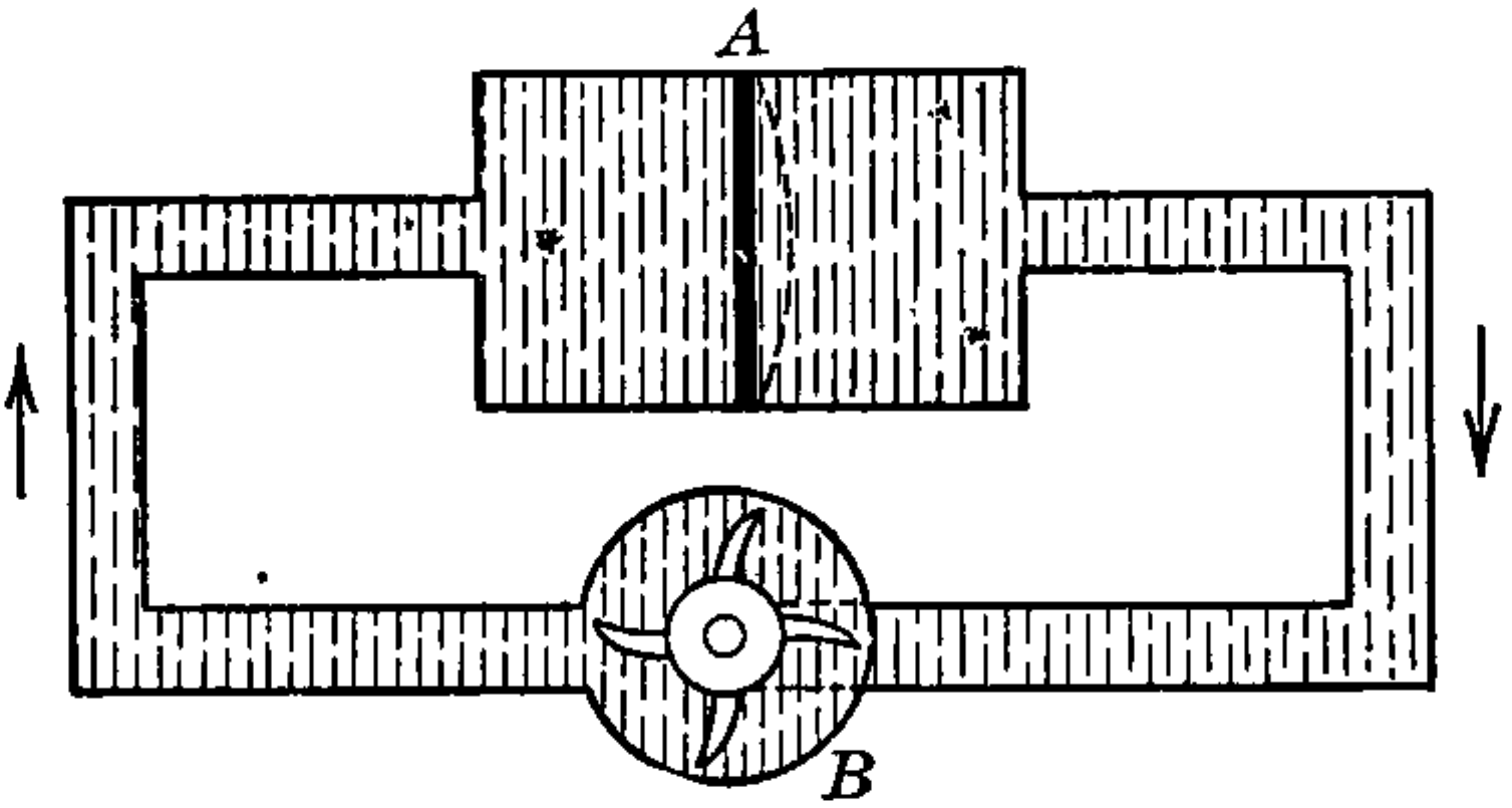

FIG. 205.

We know from experience that an insulator of any kind stops the flow of a direct current, while a condenser if of large capacity offers a very low impedance to the flow of an alternating current. Consider an arrangement as shown in Fig. 205, in which *B* represents any form of pump which tends to force water around the circuit as shown by arrows. *A* is a reservoir with an elastic diaphragm stretched across the middle. When the pump is started the

positions. Their displacement depends upon the potential of the battery and is analogous to the deflection of the diaphragm in the water reservoir. In such a circuit current flows until the potential difference across the condenser is equal to the voltage of the battery. The quantity of electricity flowing into the condenser depends directly upon its capacity and upon the voltage of the battery. For each unit that flows into P an equal amount flows out of P'. This flow is called a displacement current, and is made possible by the slight displacement of the electrons in the dielectric. In the case of the water reservoir the deflection of the diaphragm increases with the pressure until rupture takes place. In the condenser the displacement of electrons, and the mechanical strain in the dielectric, increases with the voltage until the dielectric breaks down. The voltage at which the breakdown takes place is called the dielectric strength of the material.

Energy of Charge in Condenser.

Work is required to produce the dielectric strain in a condenser, and when the condenser is charged this strain represents potential energy. In pumping water into a tank or standpipe the work done is equal to the weight of water times the average height to which it is pumped. Height in this case is a measure of pressure. Expressed as an equation, Work $= \frac{1}{2} WH$. In charging a condenser to a maximum potential of E, the average potential, or electric pressure, is $\frac{1}{2} E$. Work done in charging is $\frac{1}{2} QE$ ergs. Since $Q = CE$, this expression can be written $W = \frac{1}{2} CE^2$, in which W is in ergs, C in farads, E in volts.

Inductance.

In Chapter I attention was called to magnetic strain in the ether surrounding a wire carrying an electric current. This strain is represented by flux lines, the shape and distribution of which is strikingly illustrated by the iron filings sprinkled on paper held in such a magnetic field. The positive direction of these lines, or the direction in which a free positive pole would move, can be determined by any of the rules familiar to the student. Perhaps the most convenient of these rules is the Right-hand Rule first enunciated by Ampère: Grasp the conductor with the right hand, thumb extended along the wire in the direction of the current, the fingers will then indicate the positive direction of the circular lines of flux or magnetic strain.

This strain in the ether, in the field surrounding a permanent magnet, is conceived to be due to the peculiar symmetrical or uniform arrangement of the molecules or atoms in the magnet. In a wire carrying current it is caused in some manner by the passage of electrons along the conductor. In either case the strained medium represents a certain amount of potential energy. The strain, or the number of flux lines used to represent it, is directly proportional to the current which produces it. In its reactive effect upon the current which produces it, this strain is analogous to the inertia or momentum of a body. An increase or decrease of current is resisted by the strain just as a moving body resists any force applied to change its speed or direction of motion. This inertia effect described above is called self-induction. Just as the inertia of a moving body differs from friction, so does self-induction differ from resistance. Resistance in a circuit or conductor is a constant factor tending to obstruct the passage of electrons. Inductive effects are present only when there is a change in current or a change in flux. A change in the number of flux lines embracing or linking with the turns of a conductor, that is, a change in the strain in the ether surrounding the conductor, causes a displacement of electrons along that conductor.

This is the principle involved in all generators of electromotive force. A conductor is caused to move through a field of magnetic strain, or the field is caused to move with reference to the conductor. Suppose a conductor to be moved through a field caused by two magnets as shown in

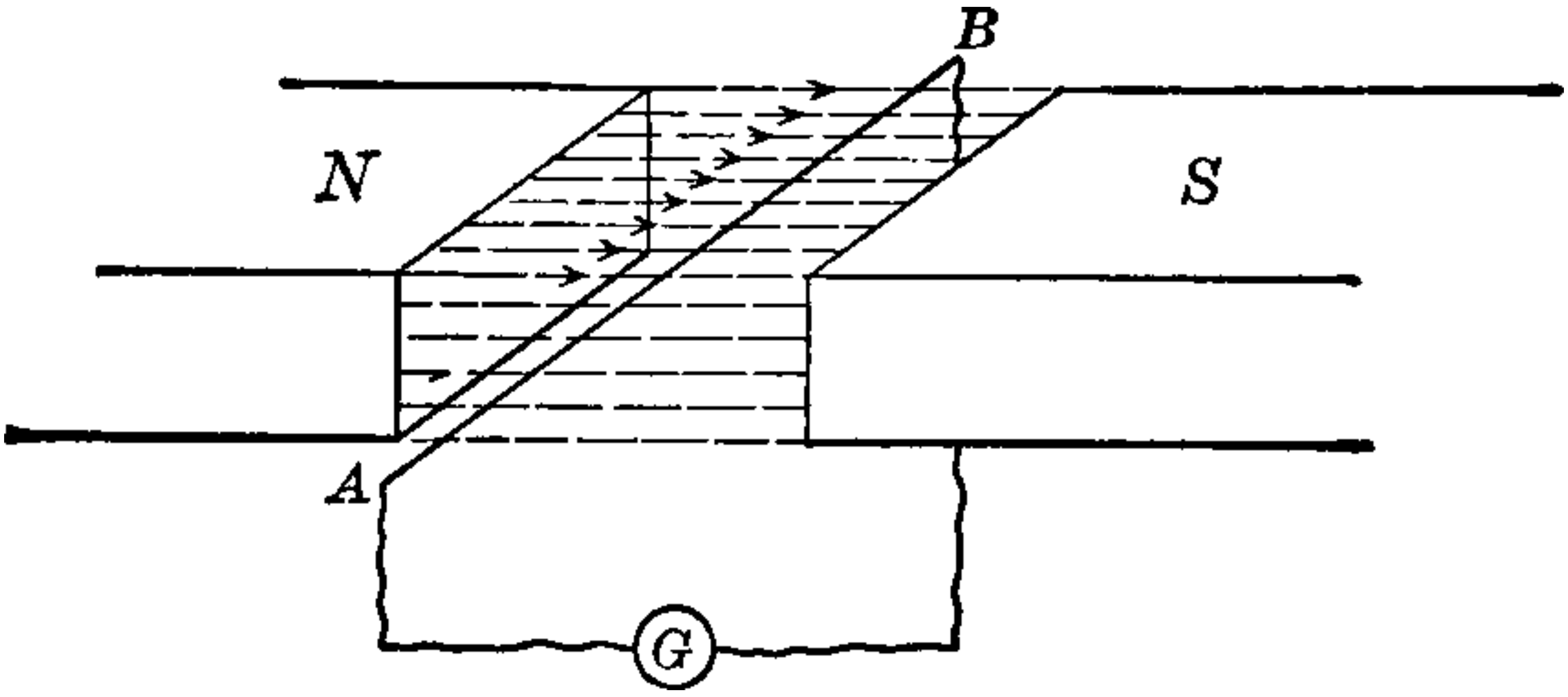

FIG. 207.

Fig. 207. The conductor is said to cut lines of force or the interlinkage is changed. By change of interlinkage we mean that the number of lines threading through the coil, or circuit, is changed.

Interlinkage of flux lines is best shown in the case of the fields of one or more coils or solenoids. The fields surrounding the elements or turns of a coil add up to give a magnetic field as shown in Fig. 208. If a second coil *B* is placed near to *A*, so that the flux of *A* passes through the turns of *B*, the flux is said to interlink with *B*. A change in the number of lines, that is a change in the field of *A*, causes an electron displacement in *B* as well as in *A*.

In any case of a changing flux, or interlinkage, the electron displacement tends to cause a current, that is, it sets up an E. M. F., in the opposite direction to that which produces the change in flux. Take for example a straight wire carrying current. An increase in current causes an increase in flux; this increase in flux or strain sets up an E. M. F. which opposes the change in current. This is called counter E. M. F. In the case of a decreasing current, hence a decreasing flux, the induced E. M. F. acts in the same direction as the original current. In the case of a coil where the flux lines embrace more than one wire, or turn, the induced E. M. F.'s in each turn add up, so that the counter E. M. F. may become very great.

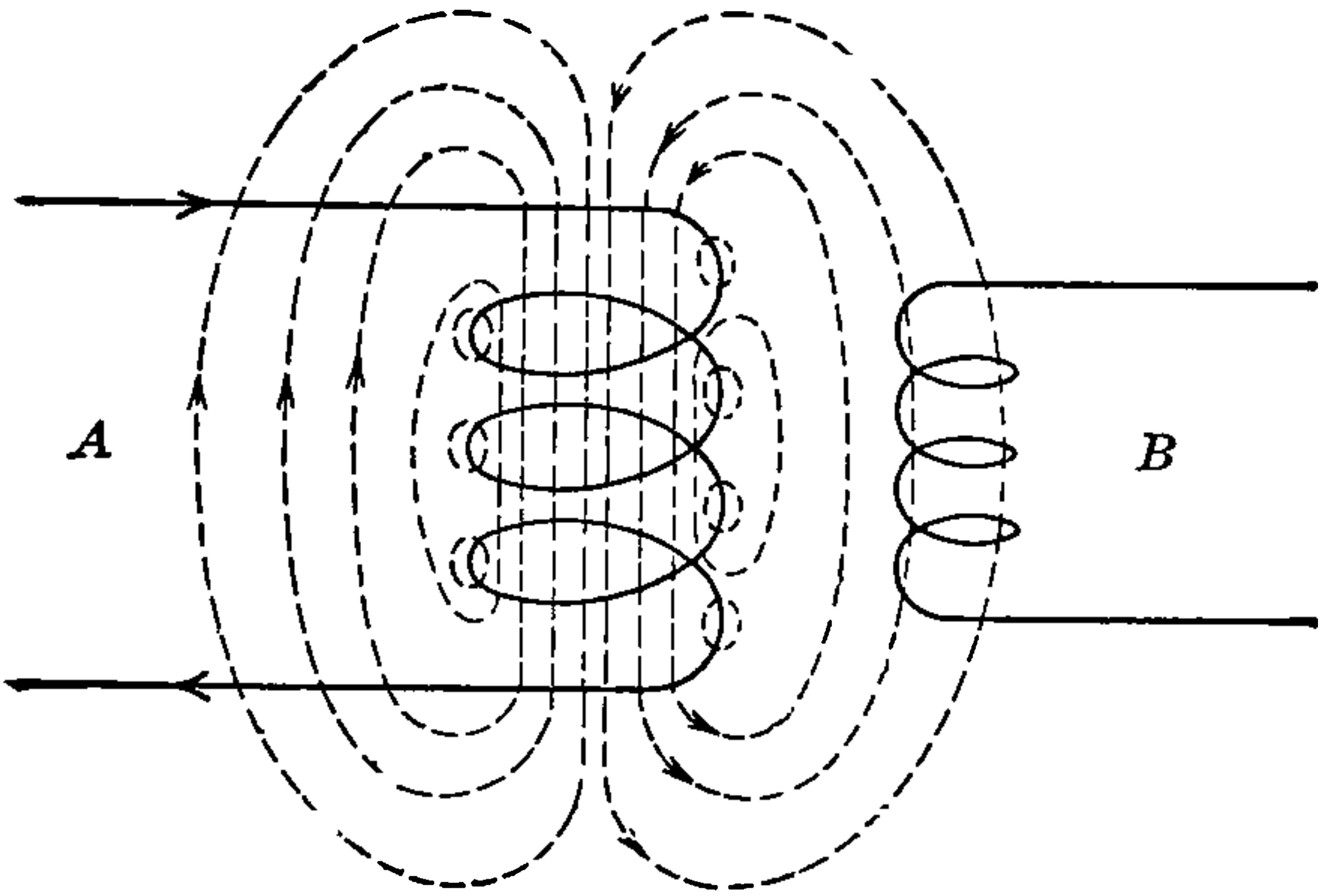

FIG. 208.—Magnetic Field of a Solenoid.

The value of this induced E. M. F. depends upon the rate of change of the flux. A sudden change in magnetic strain produces a great displacement of electrons. This is a point to be remembered by radio students. In the study of alternating current the student has been shown that the reactance of a coil increases with the frequency. A coil that would permit considerable flow of current at any frequency met with in alternating current work might have such a relatively high counter E. M. F. induced, when used with the extremely high frequencies of oscillating currents that no appreciable current would flow. Such coils are called choke coils, and are used to choke off high frequency currents and to pass current of low frequency when this is desirable.

The unit of self-induction is called the Henry. A coil or wire is said to have an inductance, or coefficient or self-induction, of one henry when a change of current of one ampere per second causes a change of flux, which in turn induces an E. M. F. of one volt. This unit is very large, so for most practical purposes we use some subdivision of the unit: millihenry, 1/1000 of a henry; microhenry, 1/1000000 of a henry.

Energy Stored in Magnetic Field.

Magnetic strain represents potential energy. If the current in an inductive circuit is increasing, part of the energy being put into the circuit is being used to overcome the inertia effects of self-induction. This energy is being stored in the magnetic field, and if after an instant the current begins to decrease the energy is returned to the circuit, tending to prevent the decrease. In the case of an alternating current the energy stored in the magnetic field during one quarter of a cycle is returned to the circuit during the next quarter. The numerical value of this stored up energy is given by the expression $1/2\, LI^2$ joules, where L is given in henries and I in amperes. The mathematical derivation of this expression will be found in Chapter XII.

Permeability.

In the study of electric strain we noted that the number of strain lines might be increased by the use of suitable dielectric material. Likewise we can increase the number of magnetic lines of force, or flux lines, by establishing the field in magnetic material, such as iron. By magnetic material we mean a material that is attracted by a magnet, or that can be temporarily given the properties of a a magnet. Iron, cobalt, nickel, and manganese are examples of magnetic materials. The ratio of the number of flux lines, due to a certain current or magnetizing force, in iron, to the number that would exist in air, due to the same magnetizing force, is called the permeability of the iron. The permeability of some grades of iron may be as high as 60,000. The number of lines of force, hence, the inductive effects noted, may be increased by causing the flux path to lie partly or entirely through iron. This increase of flux, due to iron core, becomes less as the frequency increases.

Mutual Induction.

When two circuits are so placed that the flux of each cuts the turns of the other, a change of flux in either circuit produces an E. M. F. in each circuit. The two circuits are then said to have mutual inductance. The unit of measurement is the same as in self-inductance, *i. e.*, the henry. Two circuits have a mutual inductance of one henry when a change of current in one circuit of one ampere per second produces in the other circuit an E. M. F. of one volt.

Circuits showing a few applications of the inductive effects noted above will be given. The interlinkage of flux lines determines the amount of inductance of a wire or coil, so various forms of coils are used. With low frequency currents the coil may be wound in several layers on an iron core. By this means it can readily be seen that the number of lines and the interlinkage is increased.

An induction coil, as shown in Fig. 209, is used to produce a high E. M. F., and was formerly used to a great extent in spark radio sets. Its operation is as follows: Current from a battery is supplied to the primary winding, which is mounted on an iron core. This produces a strong flux which links the primary and also the secondary winding, which is mounted concentrically with, but outside the primary. The iron core is magnetized and attracts the armature *A*. As soon as *A* moves to the left the primary circuit is broken, the flux lines suddenly collapse, and this sudden change acting upon the secondary, which consists of a large number of turns, induces in the secondary a very high E. M. F. As soon as the field collapses the core is demagnetized and *A* is drawn by a spring to its original position, the circuit is completed and operation is repeated.

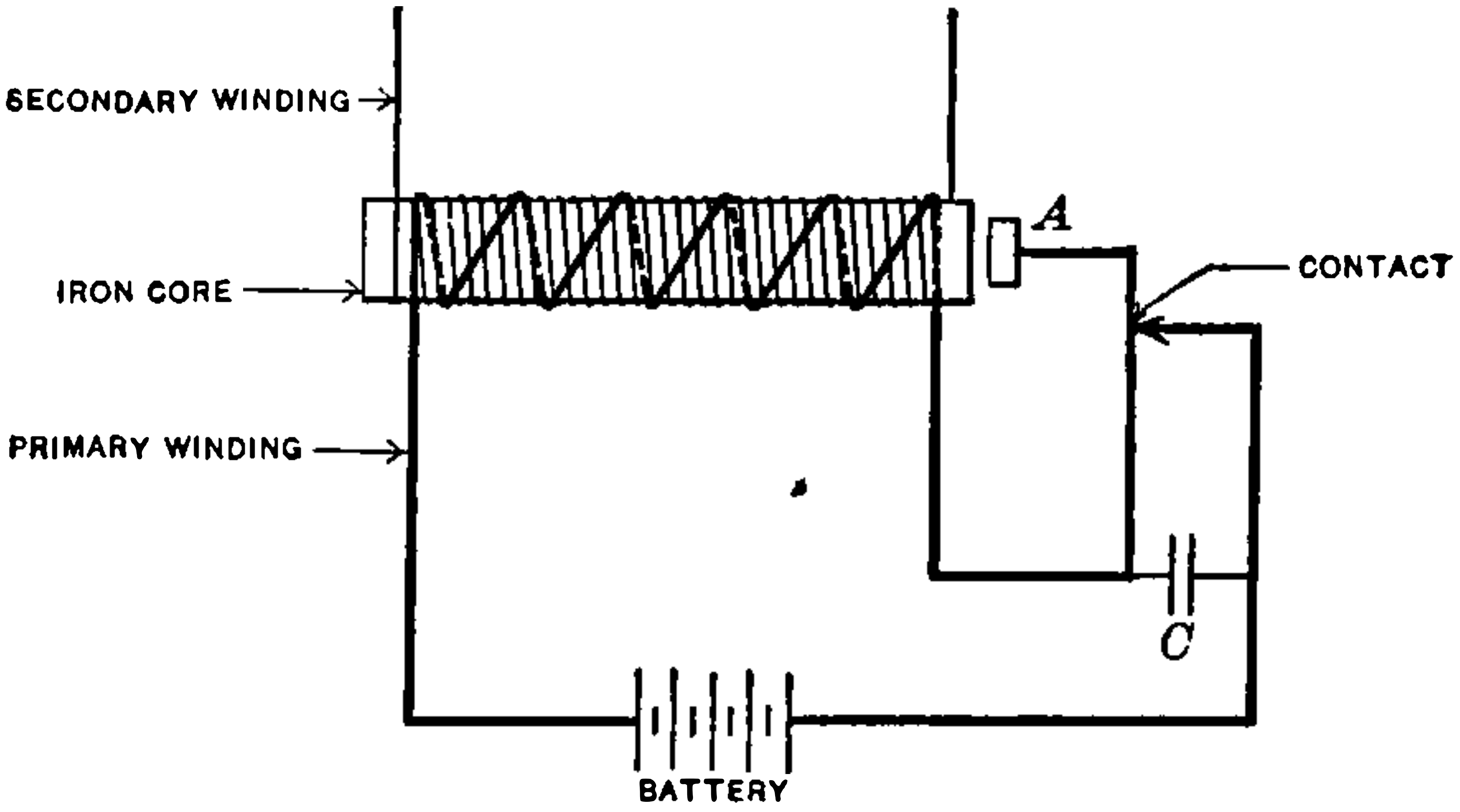

FIG. 209.—Induction Coil.

In modern radio sets, instead of supplying battery current to a circuit containing a make-and-break arrangement

CHAPTER III.

OSCILLATING CIRCUITS. FREQUENCY. DECREMENT. WAVE PROPAGATION. WAVE METERS. DETECTORS.

Oscillating Circuits.

To Prof. Henry, of Princeton University, is due the discovery that under certain conditions the discharge of a condenser, through an inductive circuit, is oscillatory in character. Later, Lord Kelvin demonstrated mathematically the relations between the inductance, resistance, and capacity that must exist in order that the discharge shall be oscillatory. This relation depends upon the condition that if all the energy stored in the condenser is used up, in I^2R losses and radiation to adjacent circuits, during one discharge of the condenser, the circuit cannot oscillate. On the other hand, if the energy is not all used up in a single discharge, the circuit will oscillate.

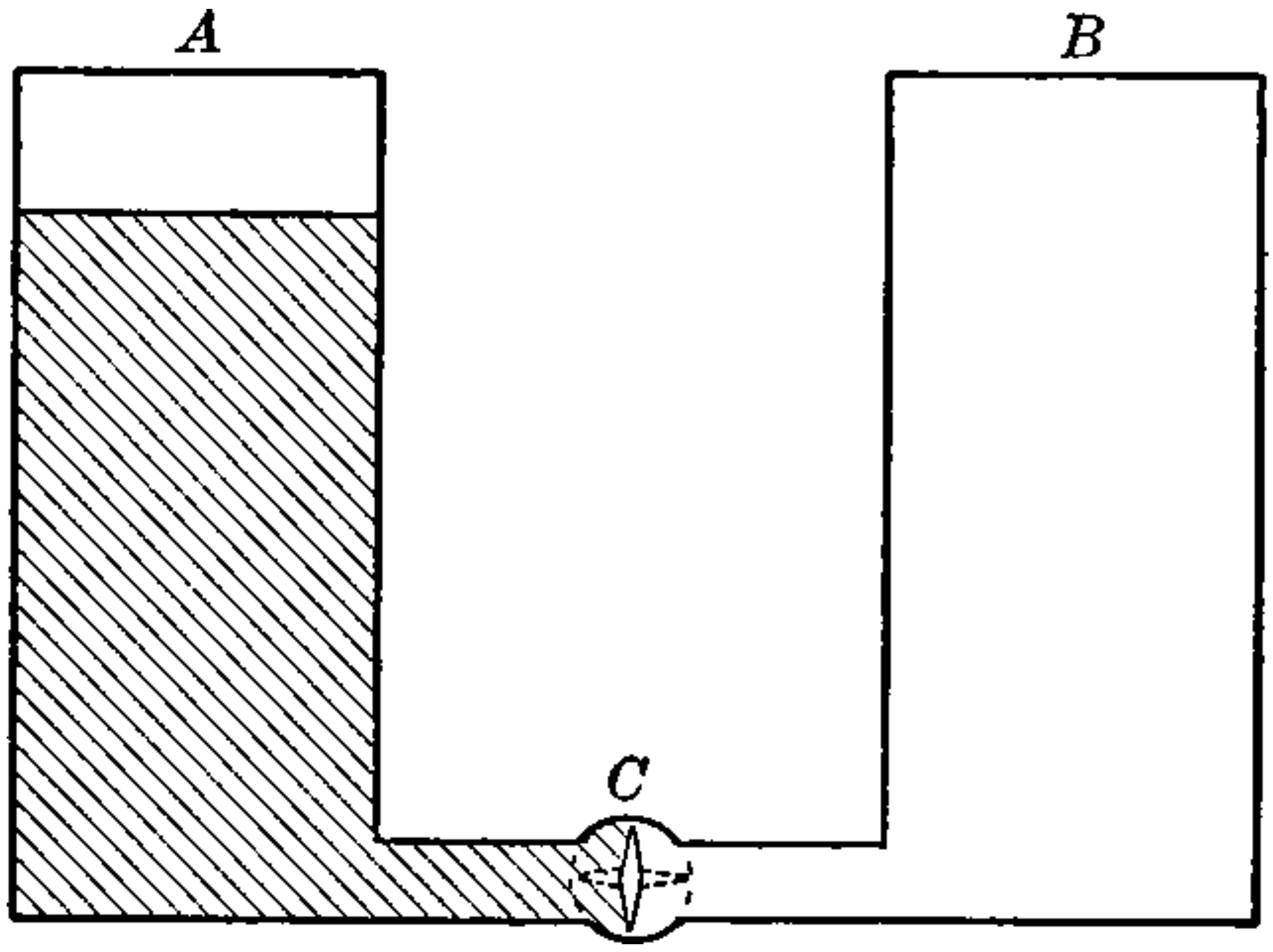

FIG. 301.

The phenomenon of oscillating circuits is analogous to the flow of water between two tanks connected by a pipe between the bases. See Fig. 301.

If the pipe connecting the tanks *A* and *B* is of large cross-section, when the valve *C* is opened the water in *A* rushes through to *B* and, due to its inertia, rises to a height almost equal to its original level in *A*, then rushes back to *A*, reaching a level slightly less than level reached in *B*. Several such surges take place before the water comes to rest with a common level in *A* and *B*. If the valve *C* is just cracked so that the passage is restricted, no surges take place, but the water level in *A* falls slowly until height in *A* and *B* is the same.

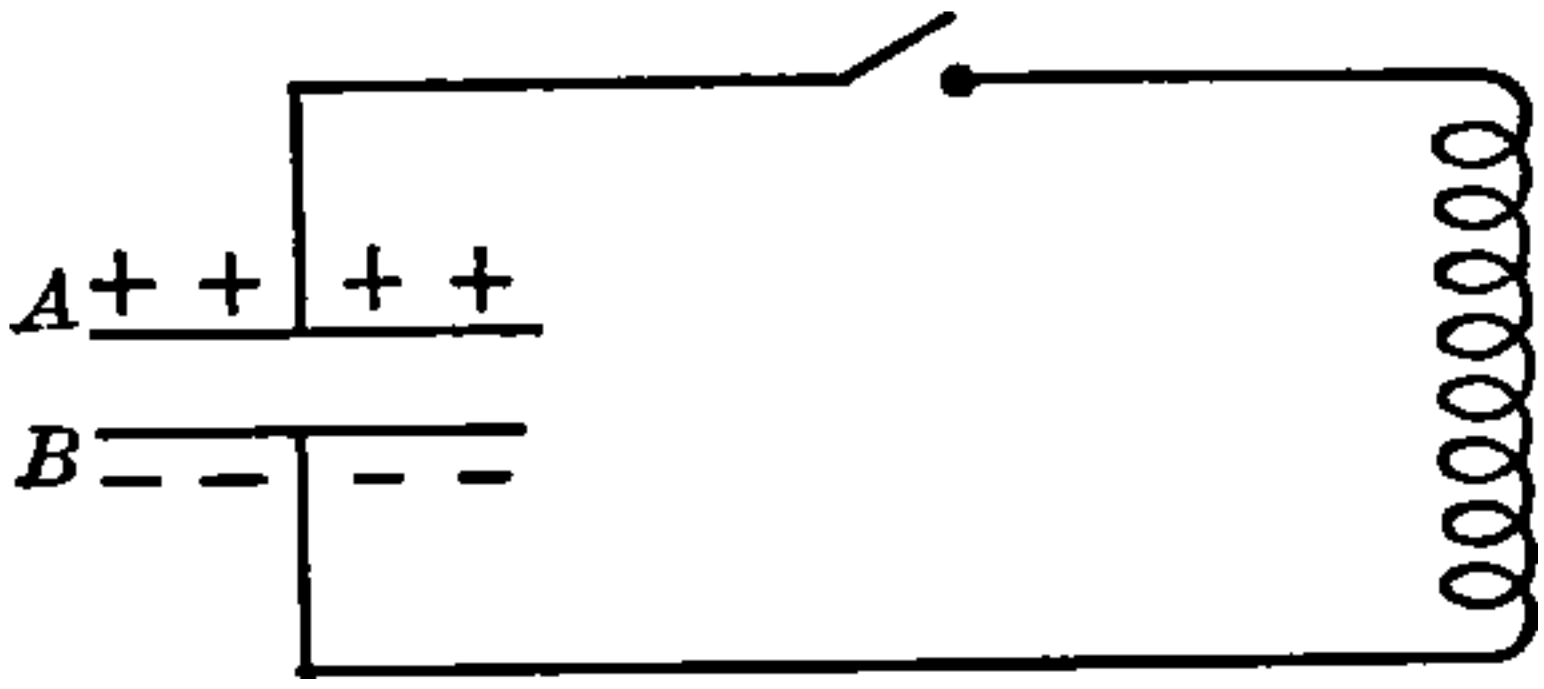

FIG. 301A.

The discharge of a condenser whose plates are connected through inductance, as shown in Fig. 301A, is analogous. Suppose the plates to be charged as indicated. If the resistance of the connecting wire is less than $\sqrt{4L/C}$ (L=inductance in henries, C=capacity of condenser in farads) the circuit oscillates, *i. e.*, when the key is closed the charge on *A* sends a current through the wire to *B*, the potential of *A* falls and that of *B* rises. When the potentials of the two plates are equal the current does not stop, but, due to the inductance, or inertia effect, continues to flow for an instant, charging the plate *B* positively and the plate *A* negatively. The current stops when the inertia effect is overcome by the accumulated E. M. F. on the condenser. The potential to which *B* is raised is not quite as high as the original potential of *A*, due to the fact that part of the energy is used up in sending the current through the resistance of the connecting wire. In the case of the water tanks, part of the potential energy of the water in tank *A* is used up in overcoming the friction in the pipes so the highest level reached in *B* is not quite as great as the original level in *A*. As soon as the inertia effects in the electric circuit have ceased, plate *B* being positively charged, the current reverses and the same operation is repeated in the opposite direction. This surging back and forth continues until the energy originally stored in the condenser has been dissipated in heat losses or otherwise.

The surging of the water is due to its inertia. The surging of electric current is due to its electrical inertia or inductance. With a given capacity and resistance, the greater the inductance the more times the current will surge back and forth.

If the resistance of the circuit is greater than $\sqrt{4L/C}$, the charge on *A* acts like the water in the tank when the valve is just cracked. It leaks out until the potentials of the two plates are equal. We have seen that the number of oscillations or surges depends upon the resistance, inductance, and capacity. The frequency of the oscillations depends upon the capacity and inductance and is determined approximately by the formula $f = \frac{1}{2\pi\sqrt{LC}}$.

The oscillating circuit in a spark transmitting set is as shown in Fig. 302. The condenser is charged by an induction coil, or by other suitable means, to a very high voltage. The spark gap in the circuit prevents any flow of current other than into the condenser until the voltage across the condenser—and across the spark gap—has reached a value sufficient to break down the air insulation of the gap. When this takes place the space between the electrodes of the gap becomes ionized, its resistance becomes very low, and oscillations take place.

It is well to study carefully what takes place in an oscillating circuit. To start with, the plates are charged as shown and all the energy in the circuit is stored in the condenser in the form of dielectric strain. When the gap breaks down and discharge begins, current through gap and coil builds up, and after a certain period no potential difference across condenser exists. The current is now a maximum and the energy is now in the form of magnetic strain in the ether surrounding the conductor. The collapse of these magnetic strain lines on the coil produces the inertia effect, resulting in a continuation of the current for an instant, thus charging the condenser with opposite polarity and establishing again the electric strain. This operation is repeated several times, but with each reversal of current the potential difference across the condenser is less and the succeeding current is less. The decrease is due to heat losses and to radiation or transfer. The current

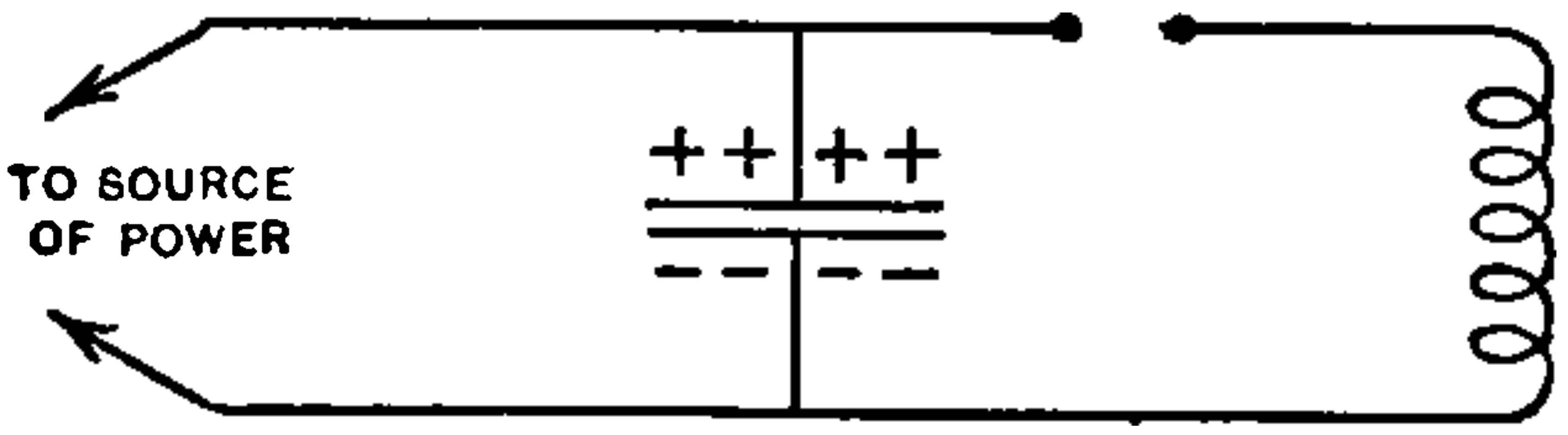

FIG. 302.—Oscillating Circuit of a Spark Transmitting Set.

flowing in the circuit may be represented by a curve, as shown in Fig. 303.

In this curve current values are plotted as ordinates against time as abscissæ. Such a current is called a damped oscillating current or, simply, damped oscillations. The ratio of the maximum ordinate of one alternation to the corresponding ordinate of the succeeding alternation in the same direction is called the damping ratio. In Fig. 304, $A/B = B/C =$ damping ratio. This ratio in a pure, damped oscillation is constant and depends largely upon the resistance of the circuit. The logarithm of this ratio to the base "ϵ" is called the log decrement. If the decrement * is large the current is said to be highly damped. If the resistance is low and the inductance fairly large the decrease in amplitude per oscillation is less and the current is said

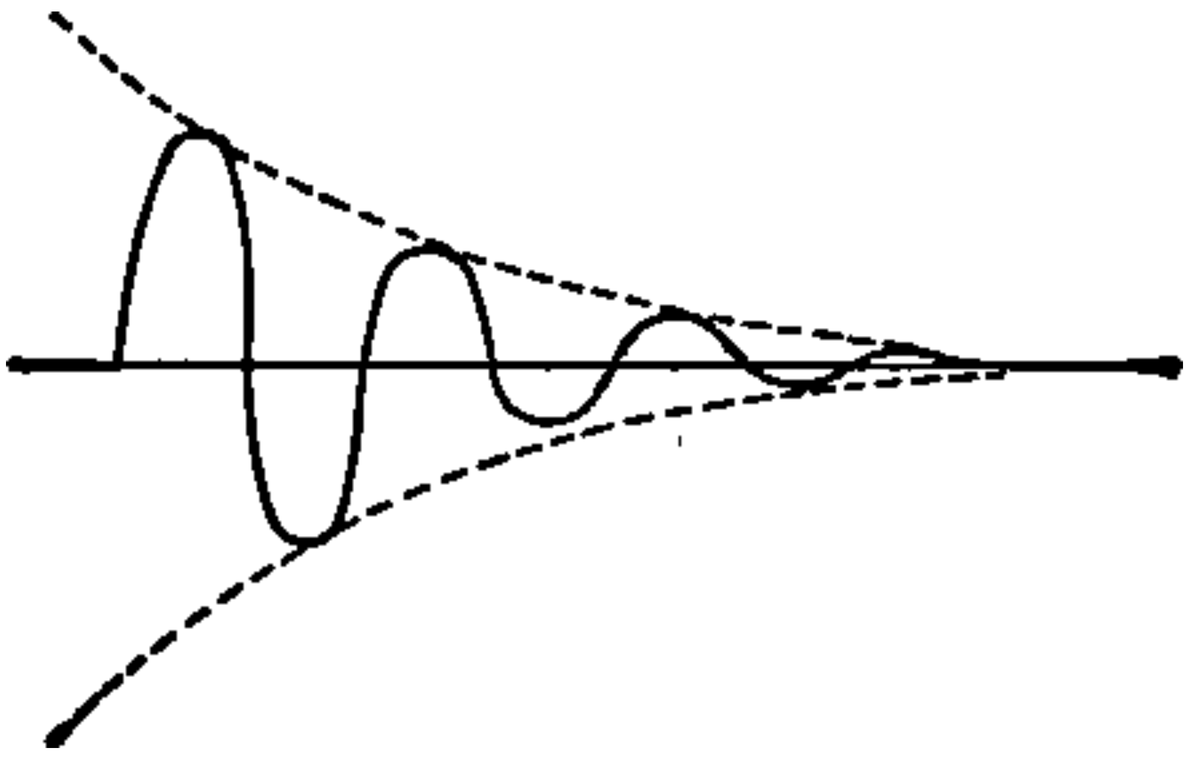

FIG. 303.

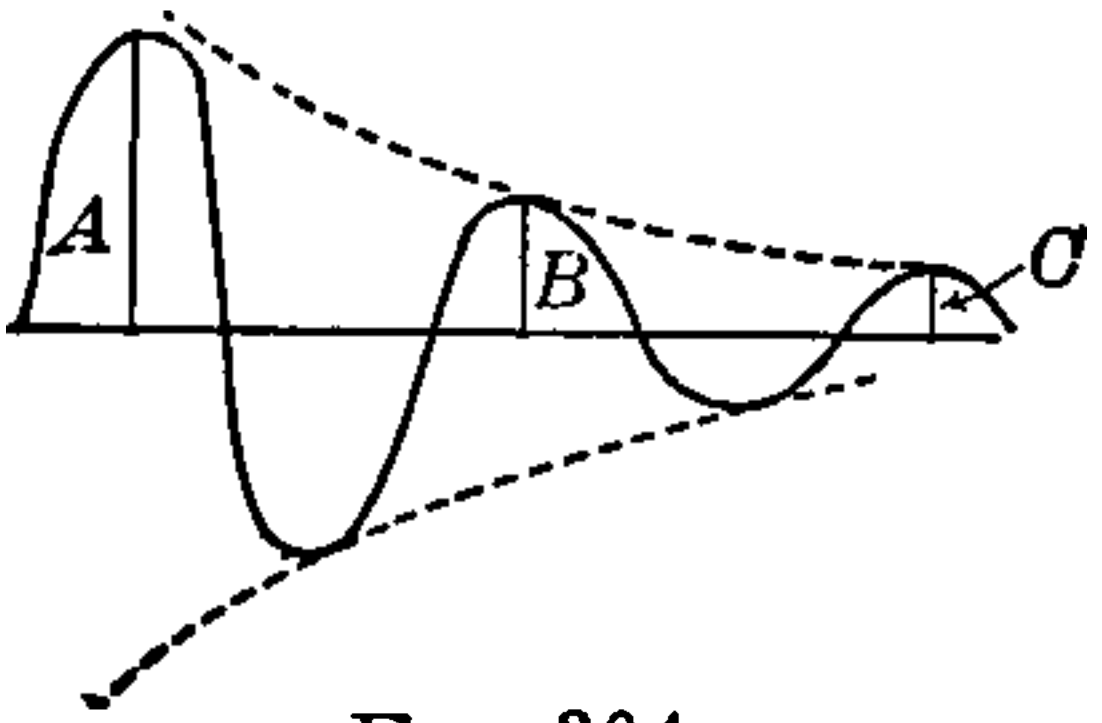

FIG. 304.

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* "Log decrement" is usually abbreviated to "decrement."

to be slightly damped. Knowing the decrement, we can compute mathematically the number of oscillations that will take place before the current dies to any given fraction of its original value.

Suppose the oscillating circuit containing a spark gap to be changed in form as shown in Fig. 305. The plates still form a condenser but, if of the same size, the capacity is much less, due to the increase in distance between them. This circuit can be made to oscillate as before change in form. Let us study the strains produced in the ether by a damped oscillating current in this circuit. At the instant before discharge begins the energy is all electrostatic, that is, stored as strain in the ether between the plates. This strain is represented by lines as shown in Fig. 306.

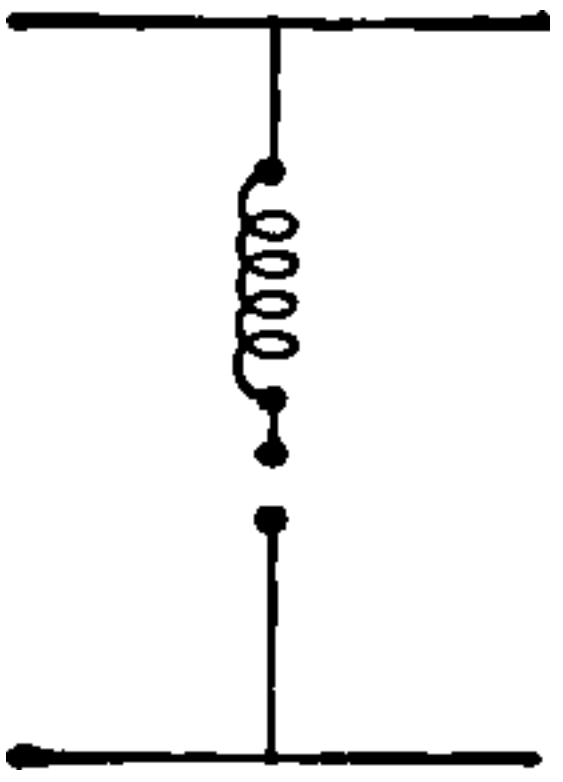


FIG. 305.

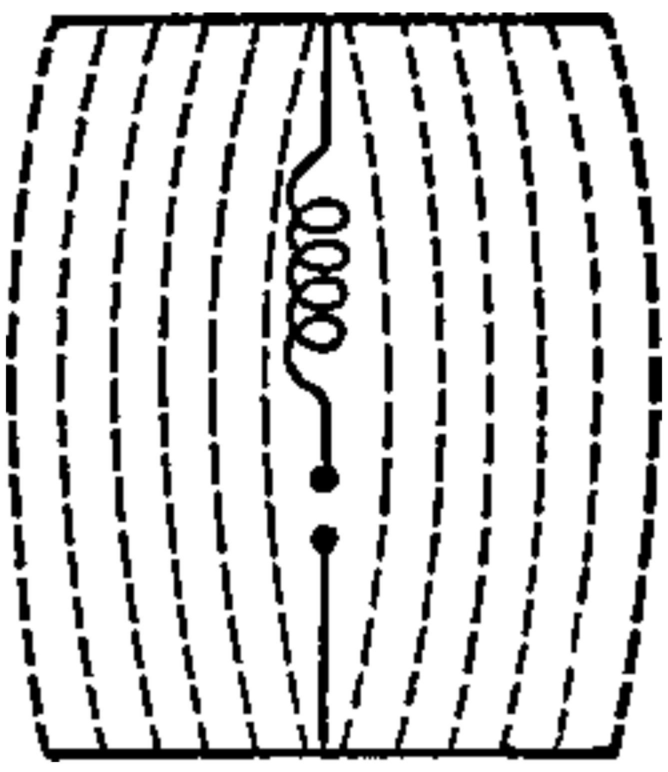


FIG. 306.

When the voltage is sufficiently high the gap breaks down, current begins to flow, and a magnetic strain is built up around the conductor. At the same time the positive and negative charges represented at the ends of the strain lines rush to meet each other and the electric field collapses. Due in part to the good conductivity of the metal plates and the conductor joining them, the ends of the long strain lines meet and the opposite charges are neutralized before the strain in the ether, represented by these lines, has been relieved. This results in closed loops of electric strain as shown in Fig. 307. This is the condition at the end of the first quarter of a cycle. The magnetic field surrounding the conductor is near its maximum value and, due to its inertia effect, is beginning to charge the plates with reverse polarity. Electric strain lines of opposite direction are beginning to form and push these strain loops out. At the end of a half cycle the condition is as shown in Fig. 308. At the end of the third quarter cycle a loop of electric strain of opposite direction has been formed. These loops of electric strain are pushed outward from the oscillating circuit with a velocity assumed to be that of light. The disturbances in the ether resulting from one oscillatory discharge form what is called a wave train.

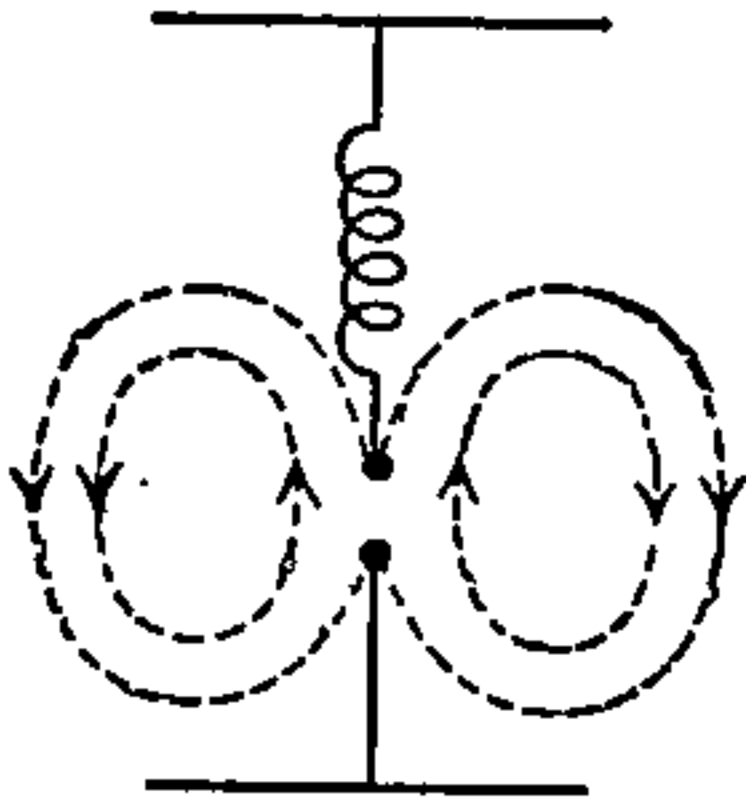


FIG. 307.

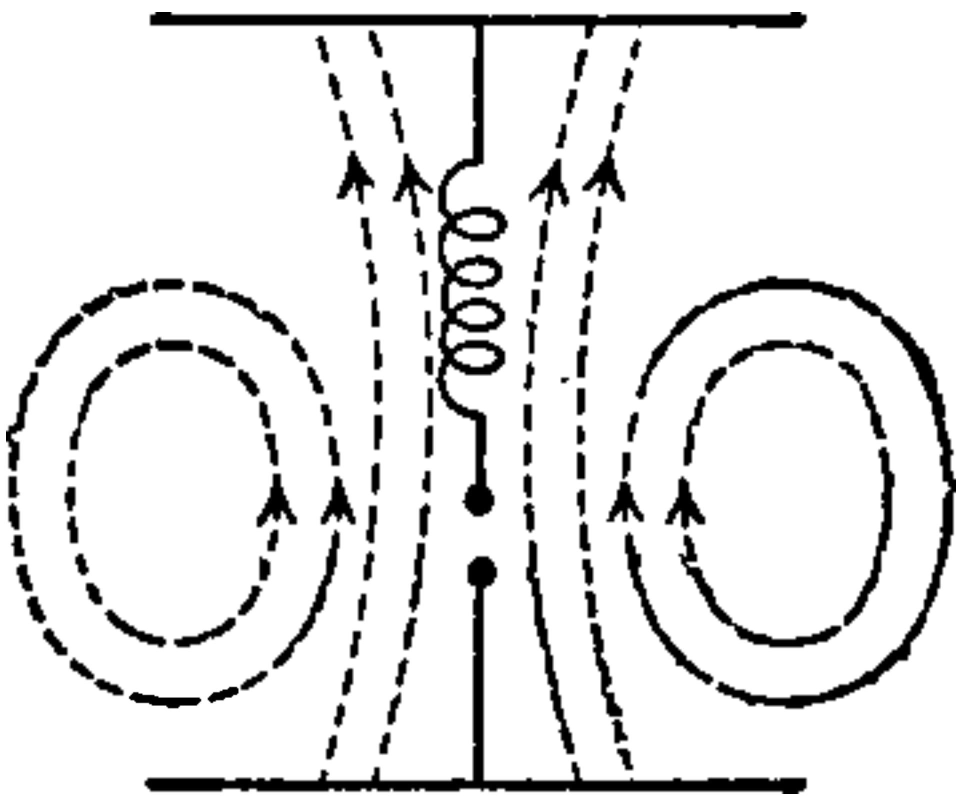


FIG. 308.

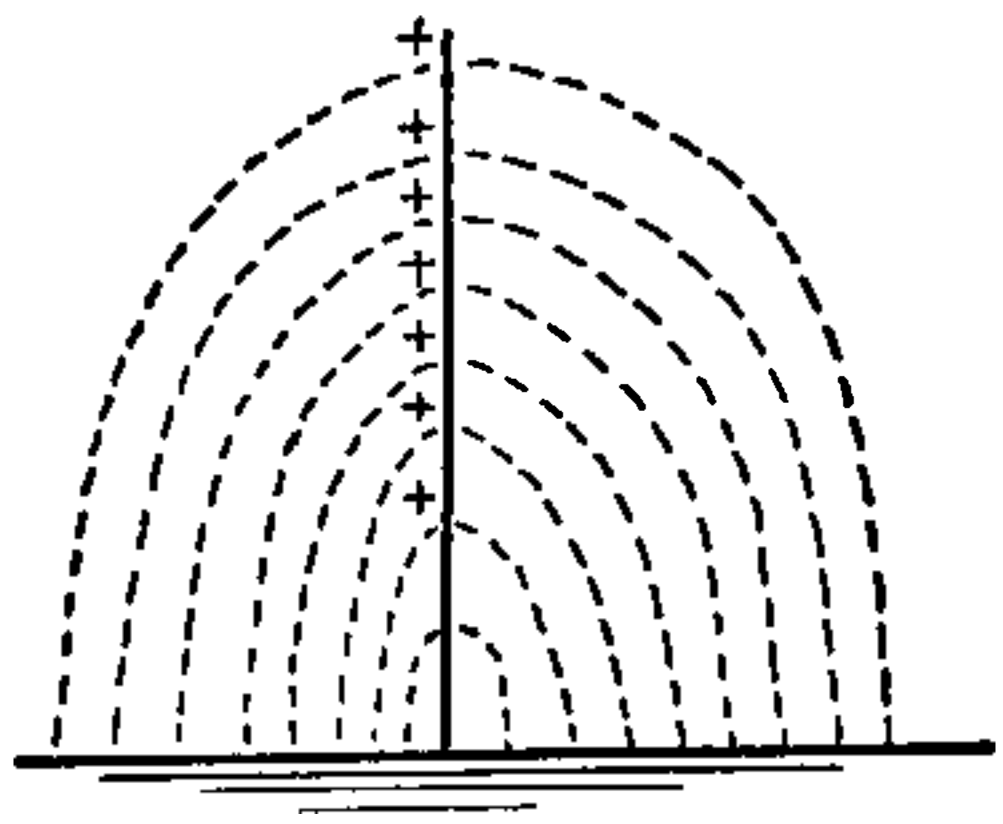


FIG. 309.

The radiation from a grounded antenna is slightly different. One end of such an antenna is grounded, hence the potential of that end is zero and the electric field is as shown in sketch of single wire antenna, Fig. 309.

equivalent to a current in the same direction as the strain lines. There must exist, then, in the dielectric, air, a displacement current in direction as stated above. These displacement currents set up magnetic strains in the surrounding ether; the variation of the magnetic strain in turn sets up electric strains in the adjacent dielectric. Since new loops of strain are constantly being formed, tending to push out those already formed, the strains resulting from the displacement currents appear to loop over outward, *i. e.,* in the direction of propagation, forming loops of increasing diameter. Fig. 312 represents the approximate shape of these waves, at some distance from the antenna. The waves are radiated in all directions from the antenna, so this sketch represents a radial section of the disturbance. The electric and magnetic strains are propagated at a velocity approximately that of light, 3×10^8 meters per second. The velocity of propagation in any wave motion is equal to frequency times wave length. In Fig. 312 the

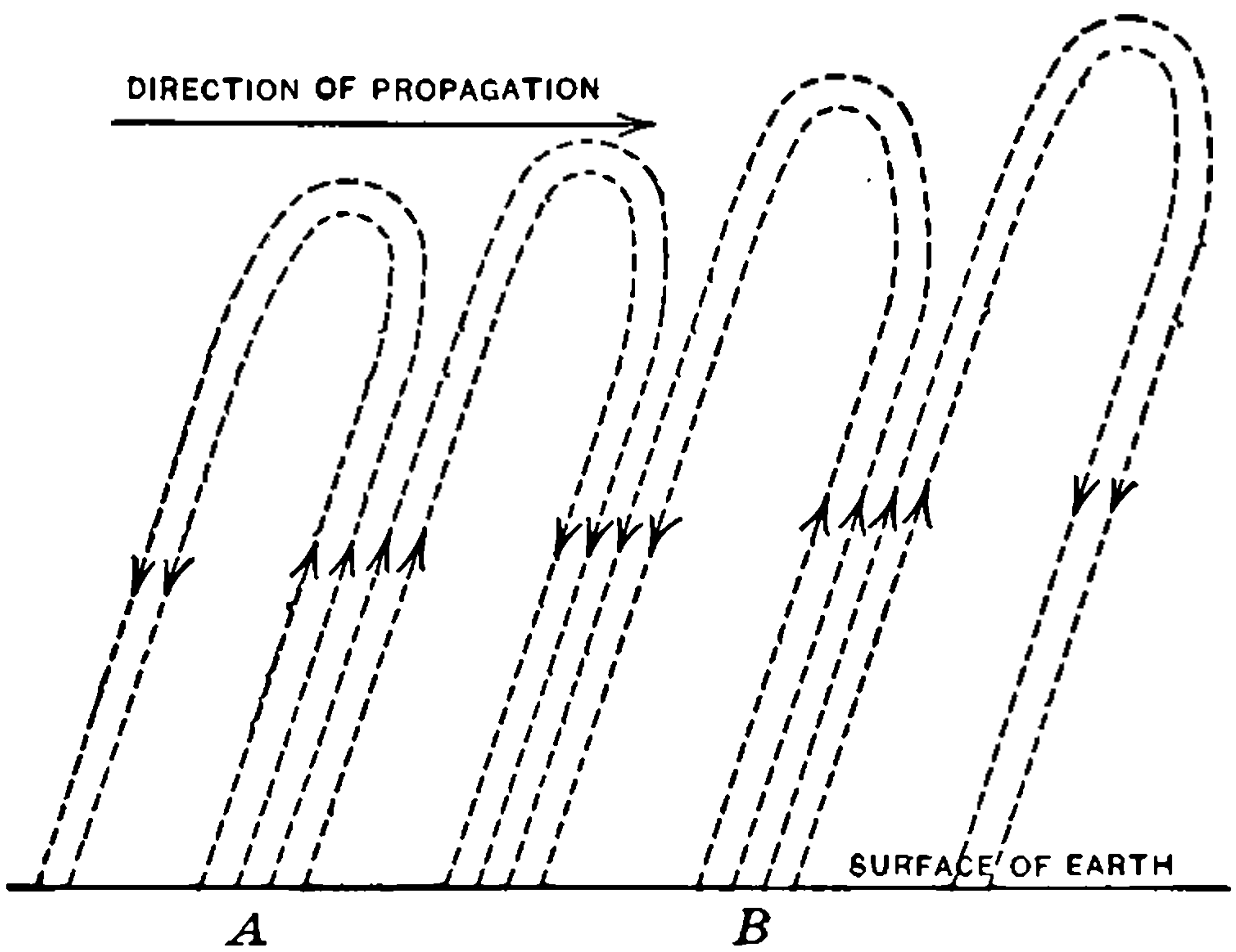


Fig. 312.

wave length is represented by *A B,* the distance in the line of propagation between like strains or between particles of the disturbed medium which are in the same phase.

The feet of these loops represent points of different potential, hence current flows along the surface of the earth between these points. This flow of current through resistance represents a loss of energy. Since there is a considerable difference in resistance of dry earth, wet earth and sea water this accounts for the difference in range obtainable over land and sea. This same resistance of the earth tends to retard the travel of the lower ends of the strain loops, hence they move more slowly than the upper ends, even though the upper ends extend into the rare atmosphere which is more or less. conductive. For this reason the loops which start out inclined slightly towards the antenna soon become inclined forward, *i. e.,* in the direction of propagation, as shown in the figure.

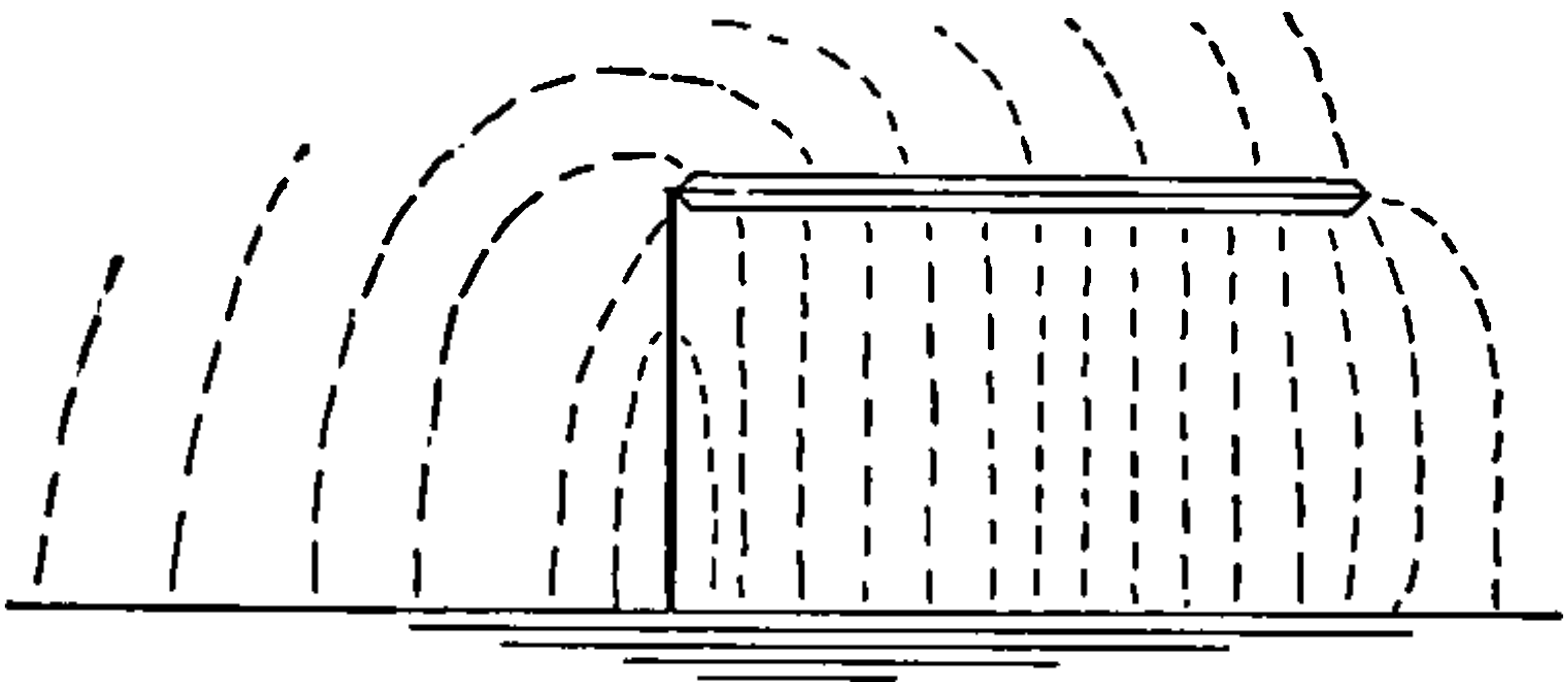


FIG. 313.

In practice we seldom use an antenna in the form of a straight wire except in airplane sets. Usually the antenna is in the form of an inverted **L** or **T** shape. The distribution of strain lines around an inverted **L** antenna is as shown in Fig. 313.

Effect on Receiving Circuits.

Let us study the effect of these waves on a receiving antenna placed in their path as in Fig. 314.

An antenna placed at *B* will be subjected to a changing electric strain and to a magnetic strain at right angles to it. Hence a difference of potential will be induced between the two ends of the antenna. A moment later the field at *B* is reversed and the direction of the E. M. F. in the antenna is reversed. The result of this E. M. F. is an oscillating current in the antenna of the same frequency as the source of the oscillations.

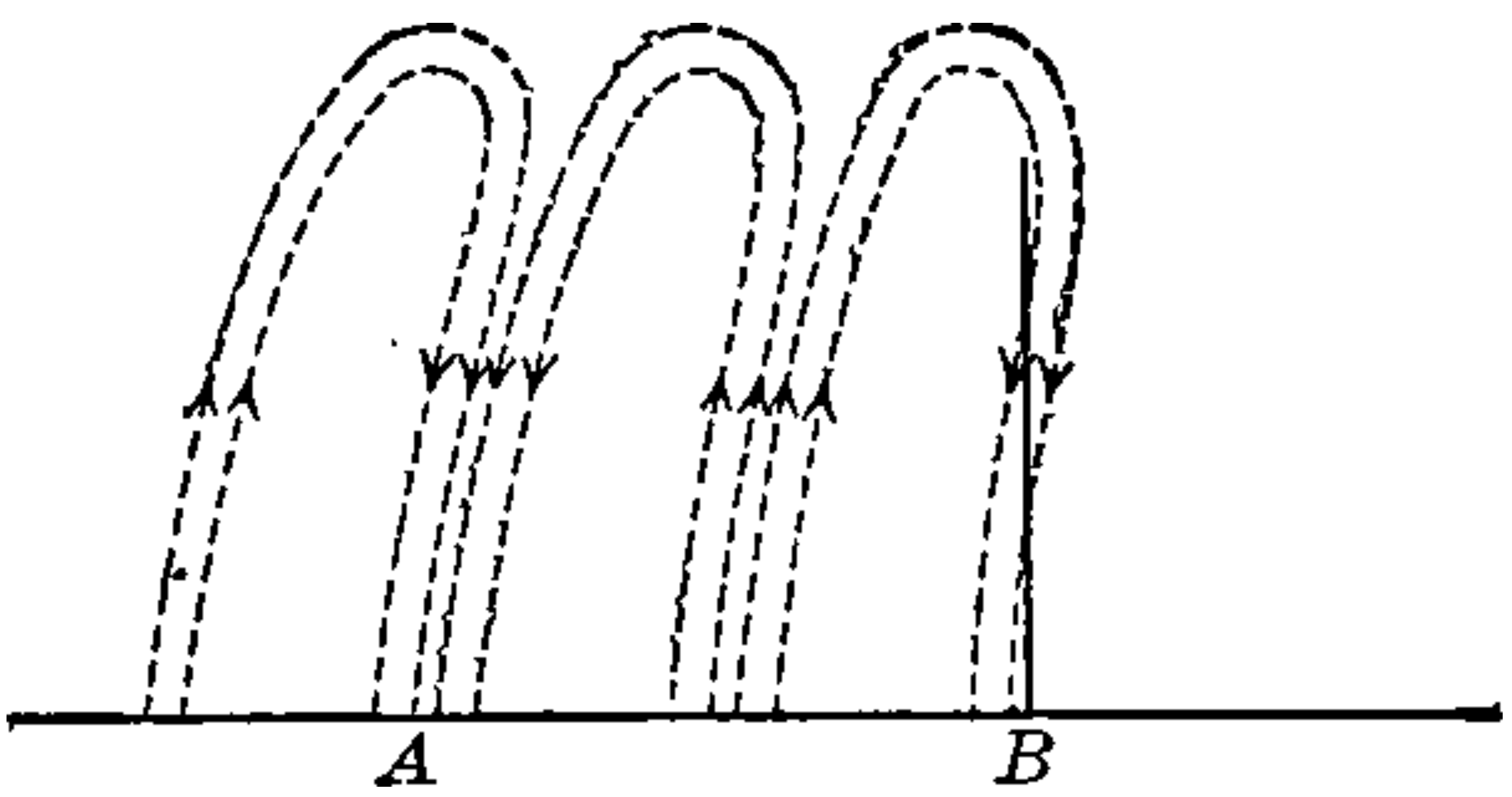


FIG. 314.

We have assumed the electric strain lines as nearly vertical. At great distances the strain lines may be inclined forward to a greater degree, and the more necessary it becomes to have part at least of the antenna horizontal. Under certain conditions and at great distances signals may be received on an antenna only a few feet from the ground and placed horizontally. At short and intermediate ranges the higher the antenna (single wire) the more length of wire is subjected to the strain and the more energy it will pick up.

Wave Meter.

As previously explained, the frequency of oscillations in a circuit consisting of inductance and capacity in series depends upon the values of the inductance and capacity, and is determined by the formula $f=1/2\pi\sqrt{LC}$. Such a circuit, in which the capacity or inductance is variable, when calibrated and marked to read frequency or wave length, is called a wave meter. Both capacity and inductance may be variable, one in steps and the other continuously. The wave length or frequency may be marked on a scale attached to the variable element or the scale may be marked in divisions or degrees and the wave length found by reference to a curve of wave length plotted against degrees or divisions. In case one element is variable by steps a separate curve is required for each step of variation.

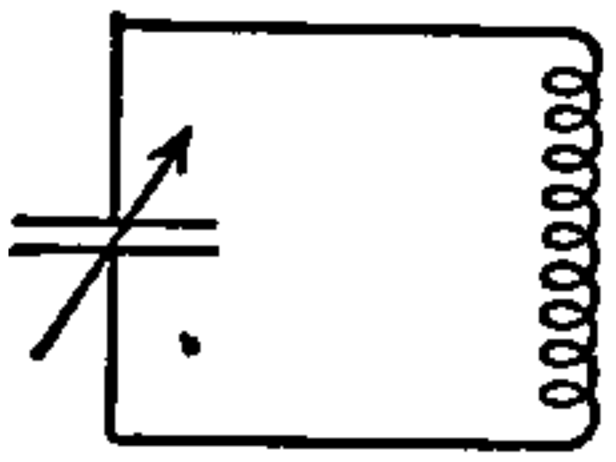


FIG. 315.
Simple
Wave Meter.

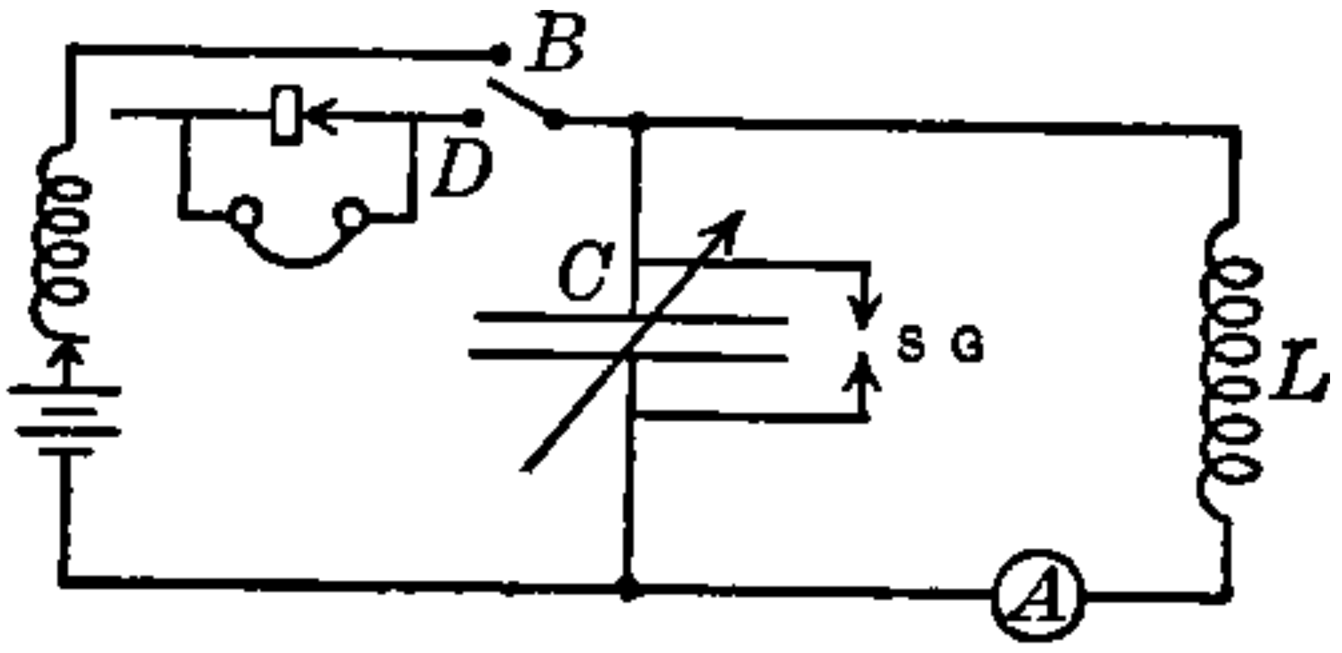


FIG. 316.

Fig. 316 shows a wave meter with the usual detecting device, safety spark gap, and buzzer and battery as used to produce, in the circuit, damped oscillations. The use of these devices will be explained in detail, partly here and later under the head of Detectors. The action of the buzzer and battery is as follows: When key is closed, connecting battery and buzzer in series across terminals of the condenser, current begins to flow from positive side of battery, through buzzer winding, inductance of wave meter, back to negative side of battery. This current through buzzer winding, which is in the form of a solenoid, causes the armature to be attracted away from the contact indicated by arrow head, thus breaking the circuit. Due to the inductance of the wave meter circuit, this current which is flowing when circuit is broken, continues to flow for an instant, charging one side of the condenser positively and the other side negatively. This is the same condition previously described under oscillating circuits. Current surges back and forth until the energy is dissipated in heat losses or otherwise. As soon as current ceases to flow through buzzer the solenoid is no longer energized and armature is returned by a spring to its former position, again making contact. However, since the make-and-break of the buzzer is very slow in comparison with the frequency of oscillations, the energy stored in the magnetic field after one break is dissipated and current ceases before the next make. Hence we get a series of wave trains as shown in Fig. 317, one wave train for each break.

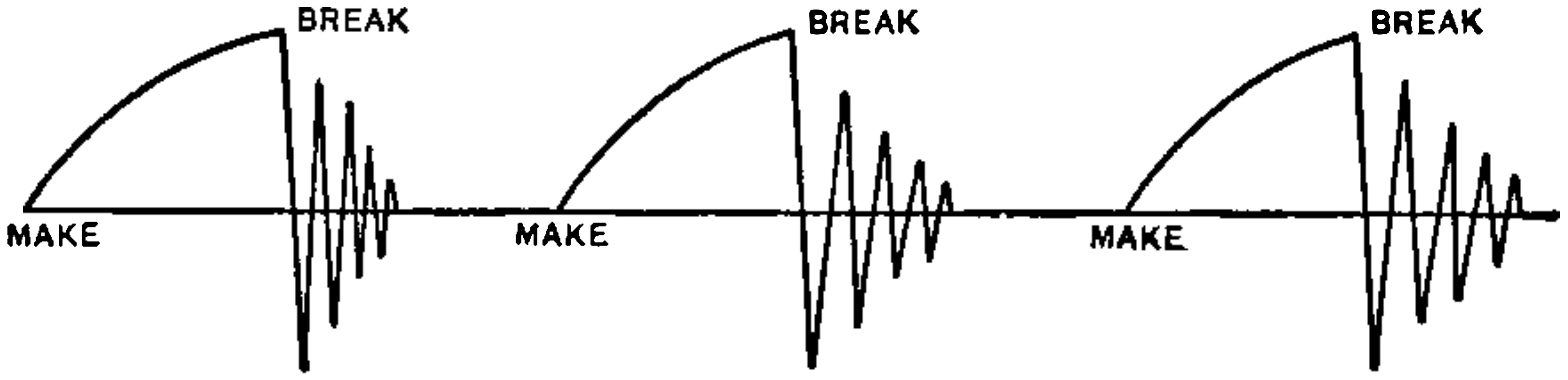


FIG. 317.

Detectors will be described in full in a later chapter, but a few words here are necessary in order that the student may understand their use in this and the following chapter. The detector here shown is a crystal of some metal or oxide in contact with a fine wire. Such a contact offers a very low resistance to the flow of current in one direction and a very high resistance to flow in the opposite direction.

Its action is analogous to that of a check valve. When the key is closed on the detector-phone circuit the E. M. F. of the condenser is impressed upon the detector. Due to the high resistance in one direction and low resistance in the other, the current which flows through the detector may be represented by a curve as shown below. The diaphragm of the phone is subjected to a series of pulls in the same direction. These pulls come at very high frequency, but the result is the same as a longer pull but of less strength.

It is readily understood that the inertia of any telephone diaphragm is too great to permit it to respond to the individual pulses of current. Even if the diaphragm could respond to the individual pulses of current the frequency would be too great for detection by the human ear. With the detector connected, as shown in Fig. 316, the frequency of clicks in the phone is equal to frequency of wave trains, which is same as "breaks" per second of buzzer. This frequency is within the range of audibility. As a matter of convenience, frequencies below 10,000 cycles per second are called audio frequencies; above that number, radio frequencies. It is possible for some human ears to detect frequencies much higher than 10,000 per second.

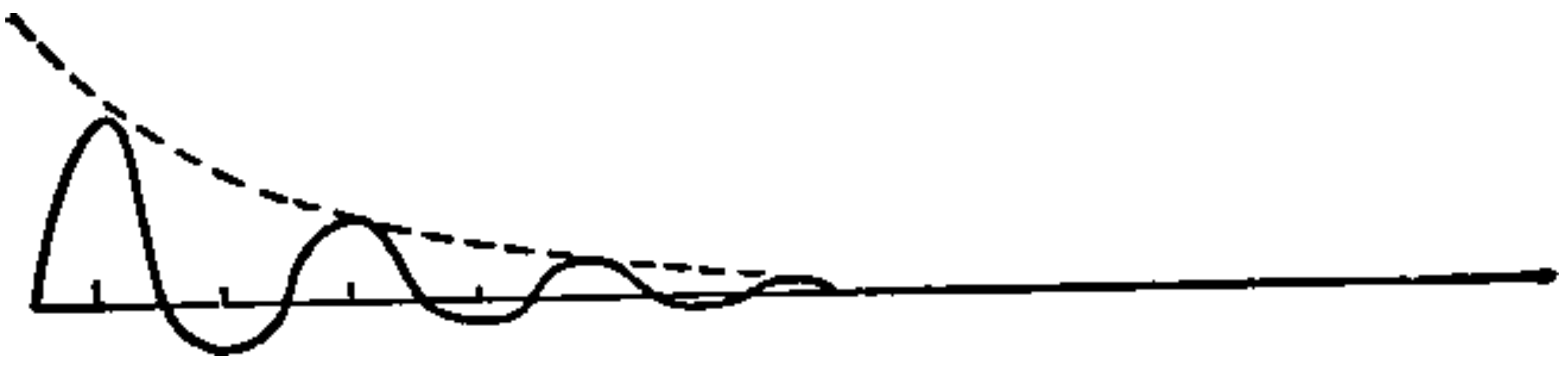


FIG. 318.

The spark gap placed around the condenser of the wavemeter serves to protect the instrument from very high voltages which might be induced in it when brought near oscillating power circuits. The gap is set to break down at a voltage much lower than would be required to damage the instrument.

The hot-wire ammeter placed in series in the circuit may be calibrated to read current directly or the divisions on the scale may be proportional to current squared, in which case the readings are proportional to the energy in the circuit.

Uses of the Wave Meter.

The wave meter is an indispensable piece of apparatus in all radio stations and laboratories. In addition to its use to produce damped oscillations of known frequency, as just described, it is used in tuning various circuits, in measuring capacity, inductance, and decrement.

To measure the wave length, or frequency, of any oscillation the wave meter is so placed that part of the electromagnetic lines of force, or flux, of the oscillating circuit cut or link with the inductive portion of the wave-meter circuit. This changing flux induces an E. M. F., and an oscillating current flows in the wave-meter circuit with a frequency equal to that of the source. As we vary the capacity, or inductance, of the wave meter we find one value at which the current in the wave meter, as measured by the sound in the phones, is a maximum. In this condition the two circuits are said to be in resonance. The frequency and the wave length are the same in the two circuits. This wave length can be read directly from the scale attached to the wave meter or from a curve of wave length plotted against condenser setting. The phenomenon of resonance can perhaps be better understood by reference to the equation familiar to students of alternating current electricity.

$$I = \frac{E}{\sqrt{R^2 + \left(2\pi f L - \frac{1}{2\pi f C}\right)^2}}.$$

CHAPTER IV.

COUPLING. TRANSFER OF ENERGY. MECHANICAL ANALOGIES.

Coupling.

Under the subject of mutual inductance and in connection with the use of the wave meter, mention was made of the fact that when the flux lines produced by a current in one circuit thread through, or cut, the turns of wire in another circuit, a change of current in the first circuit produces an E. M. F. in the second circuit. If the second circuit is closed conductively, current flows in it with a frequency equal to the frequency of periodic changes of current in the first circuit. If the second circuit is closed through capacity we may have, in addition to the forced oscillation of above frequency, free oscillations of a frequency depending upon the inductance and capacity of the second circuit.

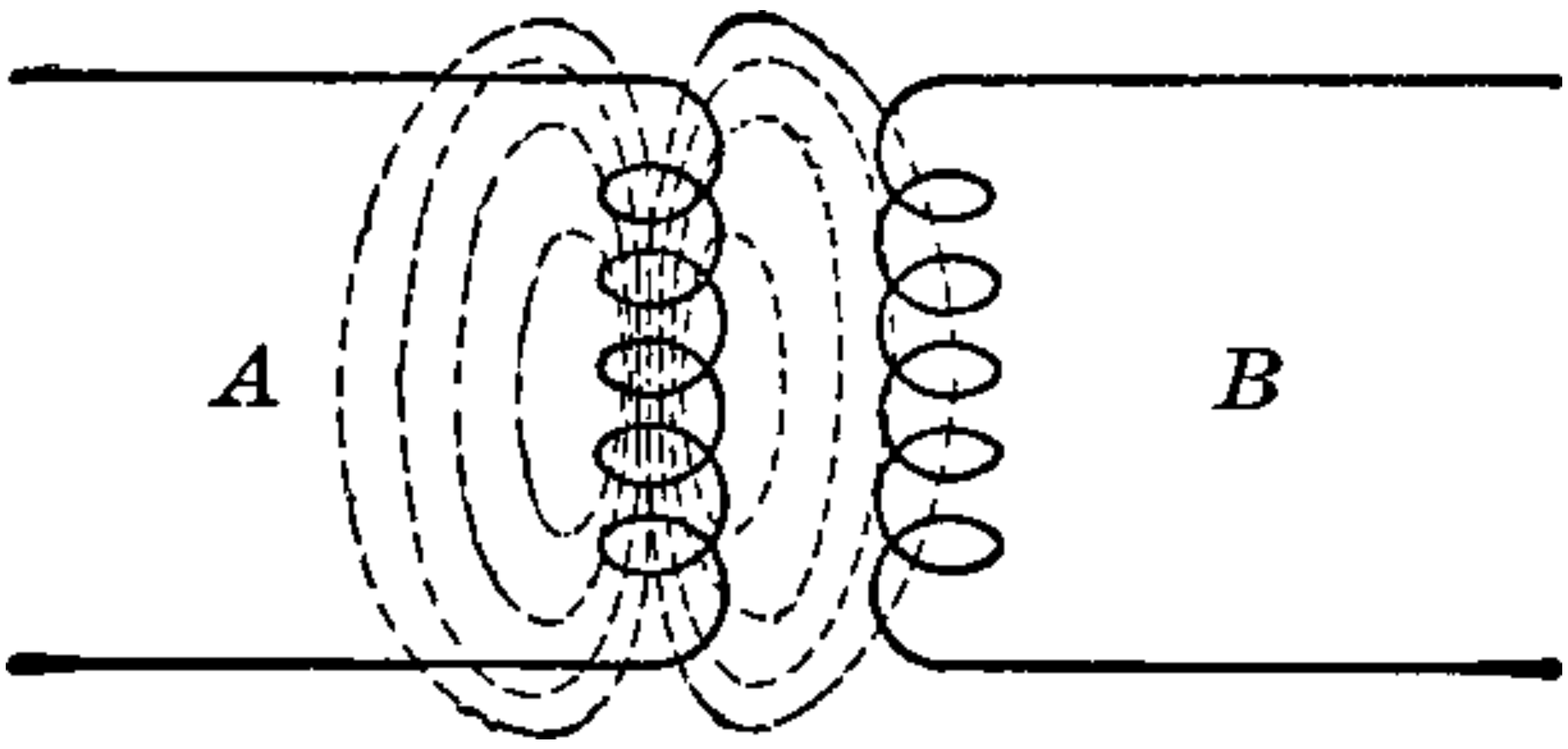


FIG. 401.

Suppose an alternating current to flow in the circuit *A*, Fig. 401. Part of the flux produced by the current in *A* links with the turns of *B*. Each change of current in *A* produces an E. M. F. in *B*. A transformer is a practical application of this principle. Any two circuits so placed that a change of current in one produces an E. M. F. in the other are said to be “coupled.” This means simply that each circuit is wholly or in part in the field of the other. The field may be electrostatic or electromagnetic. Thus we have several forms of coupling: Direct, in which the two circuits have some part in common; inductive, when the transfer of energy is effected by electromagnetic lines of force; capacitive, when electrostatic lines are used to convey the energy.

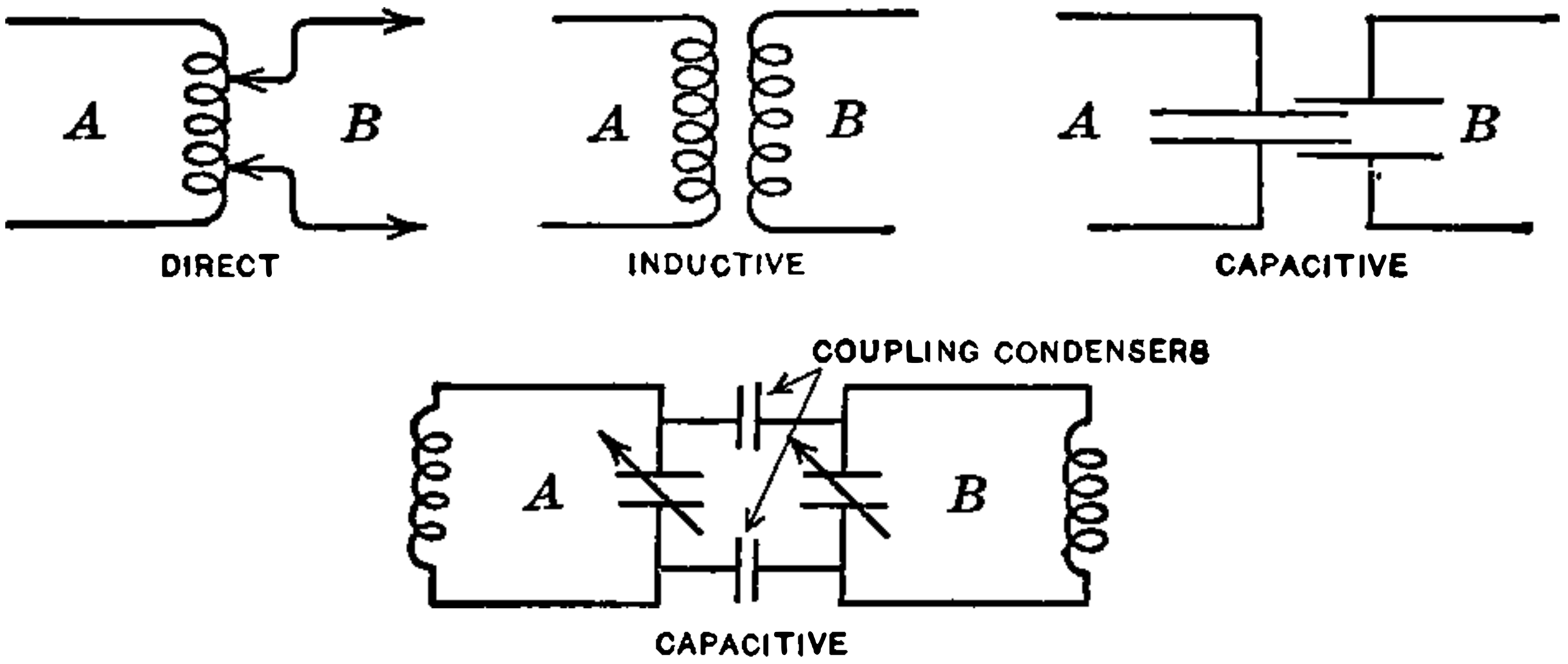


FIG. 402.—Forms of Coupling.

It can readily be seen that the greatest E. M. F. will be induced in the secondary when the greatest number of flux lines of the primary are cut by the turns of the secondary. The circuits are then said to be close coupled. The current in the secondary will be a maximum when the natural frequency of the circuit as determined by the formula $f=1/2\pi\sqrt{LC}$, is the same as the frequency of the source; in other words when the circuits are in resonance.

The condition for maximum E. M. F., that is, close coupling, is desirable for some purposes, such as transformers in power circuits. In certain radio circuits, in which damped oscillations are produced, close coupling has disadvantages, to be studied later, which make it desirable to "loosen" the coupling, that is, arrange the circuits so that only a small part of the flux of the first circuit links with the turns of the second circuit. This may be accomplished in direct coupling by reducing the portion that is common to both circuits, and in inductive coupling by increasing the distance between the coils or by turning one coil relative to the other so that the axis of one coil is nearly at right angles to that of the other. This decreases the interlinkage. To loosen the coupling in capacitively coupled circuits we usually decrease the capacity of the coupling condensers.

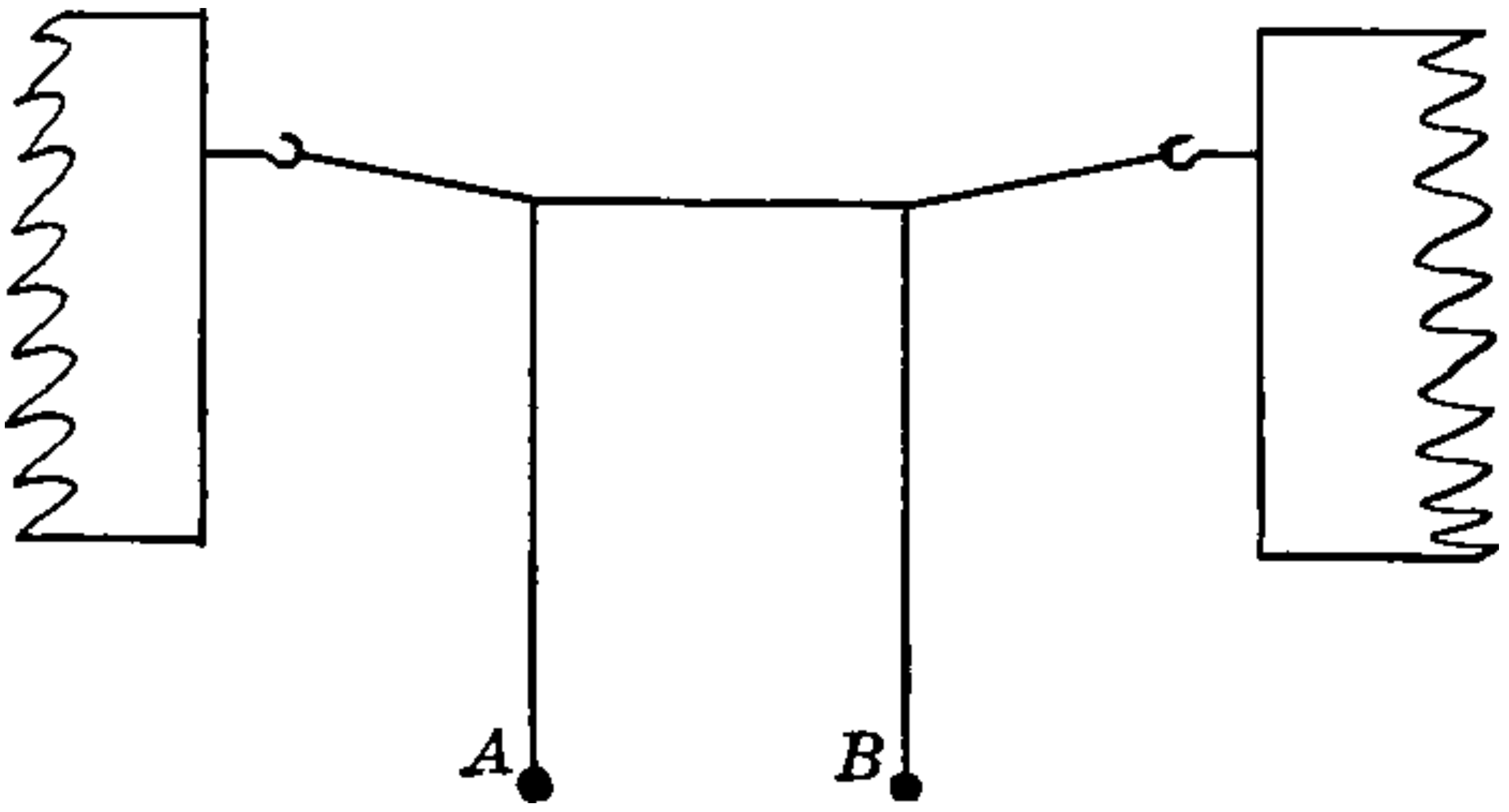


FIG. 403.

Before studying in detail the transfer of energy between coupled circuits, let us consider a simple mechanical analogy. Suspend two bobs of equal weight, by strings of equal length, from a flexible support such as shown in figure. The periods of oscillation of the two pendulums, swinging independently of each other, are the same. Start one bob to swinging by drawing it aside about 30 degrees and releasing it. After a few swings the other bob will take up the motion, and in a few moments the first bob will come to rest. At this instant the second bob will be swinging at a maximum amplitude. The operation now reverses. The first bob again takes up the motion, while the second gradually comes to rest. The energy originally imparted to the first bob is transferred back and forth until dissipated by the friction of the air, etc. The agent by which the transfer is effected is the flexible support, in this case a horizontal string. At each swing of either pendulum the horizontal string is deflected, at the point at which the bob is supported, in the direction in which that bob is swinging. This deflection tends to displace other points along the string, including the point of support of the other bob. Now displacing the point of support of any pendulum has the same effect, so far as producing oscillations is concerned, as drawing the bob to one side, as we did in the first case. Next increase the distance between the points of support of the two pendulums and repeat the experiment. It will be found that less energy is transferred—amplitude attained by second bob is less—and that the rate of transfer is slower. If we count the oscillations per second of each bob we will find that the bob that is transferring energy to the other is oscillating at a rate slightly slower, and the one receiving energy, at a rate slightly faster than that at which either would oscillate when swinging independently, or from a rigid support. In other words, neither pendulum oscillates exactly with its natural frequency.

The flexible support serves as a coupling betwen the pendulums. The distance between the points of support is a measure of the degree of coupling.

The transfer of energy between coupled electric circuits is very similar to the phenomenon just explained.

Suppose we tune the circuits *A* and *B*, Fig. 404, independently to the same frequency and couple them as shown. Produce in *A* damped oscillations by connecting to terminals of condenser a source of E. M. F. The oscillating current in *A* will induce in *B* similar currents, but neither circuit will oscillate with the frequency to which it was tuned independently. The changing magnetic flux in *A* produces an E. M. F. in *B*. The resulting current in *B* causes a flux which reacts on *A*, with or against the flux of *A*. This in turn effects the frequency of oscillations in *A*. There is a transfer of energy back and forth as with the pendulums.

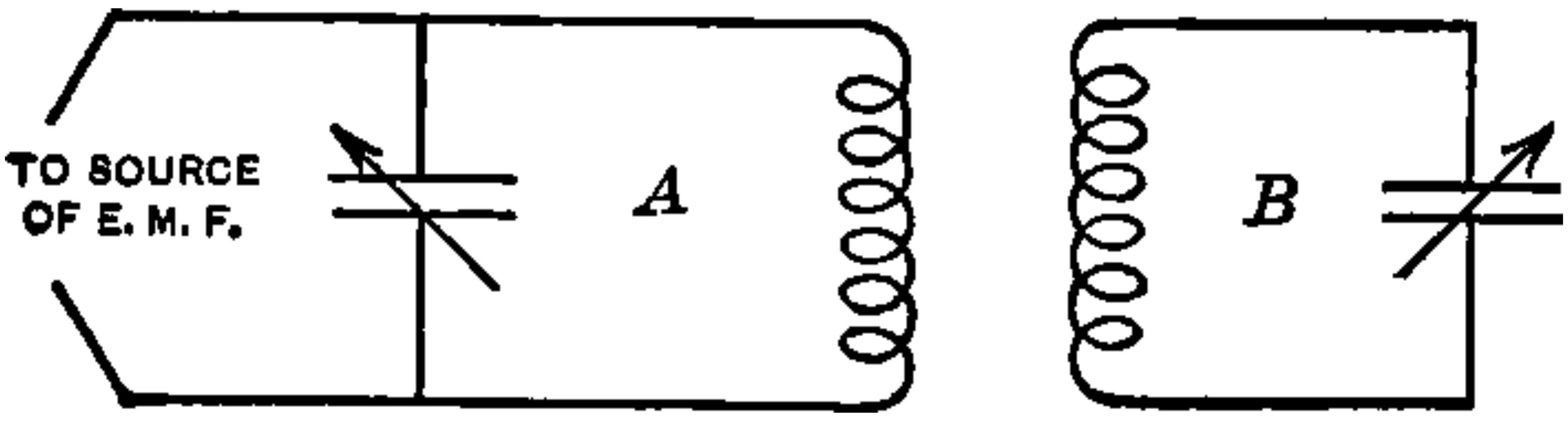


FIG. 404.

The curents flowing in these circuits may be represented by the curves of Fig. 405. As, in the pendulum analogy, the maximum amplitude of one bob was attained when the other was practically at rest, so, in the electric circuit, the maximum amplitude of current in one circuit is reached when the current in the other has died practically to zero.

To start with, the energy is all in one circuit. After a few oscillations the energy in the first circuit is dissipated by heat losses and by transfer to the other circuit and the oscillations cease. At this instant the second circuit, with maximum current flowing, begins to transfer energy back to the first. All current in the first circuit represented by that part of the curve to the right of the point *A* is produced by a re-transfer of energy. Due to the I^2R losses and to slight radiation the total energy is constantly decreased until oscillations in both circuits cease.

As was mentioned above, coupling two circuits which are tuned to the same wave length tends to cause two different wave lengths to be produced in this system whenever *one* of them is excited. One of these waves will be longer and the other shorter than the wave length to which the individual parts of the circuit are tuned.

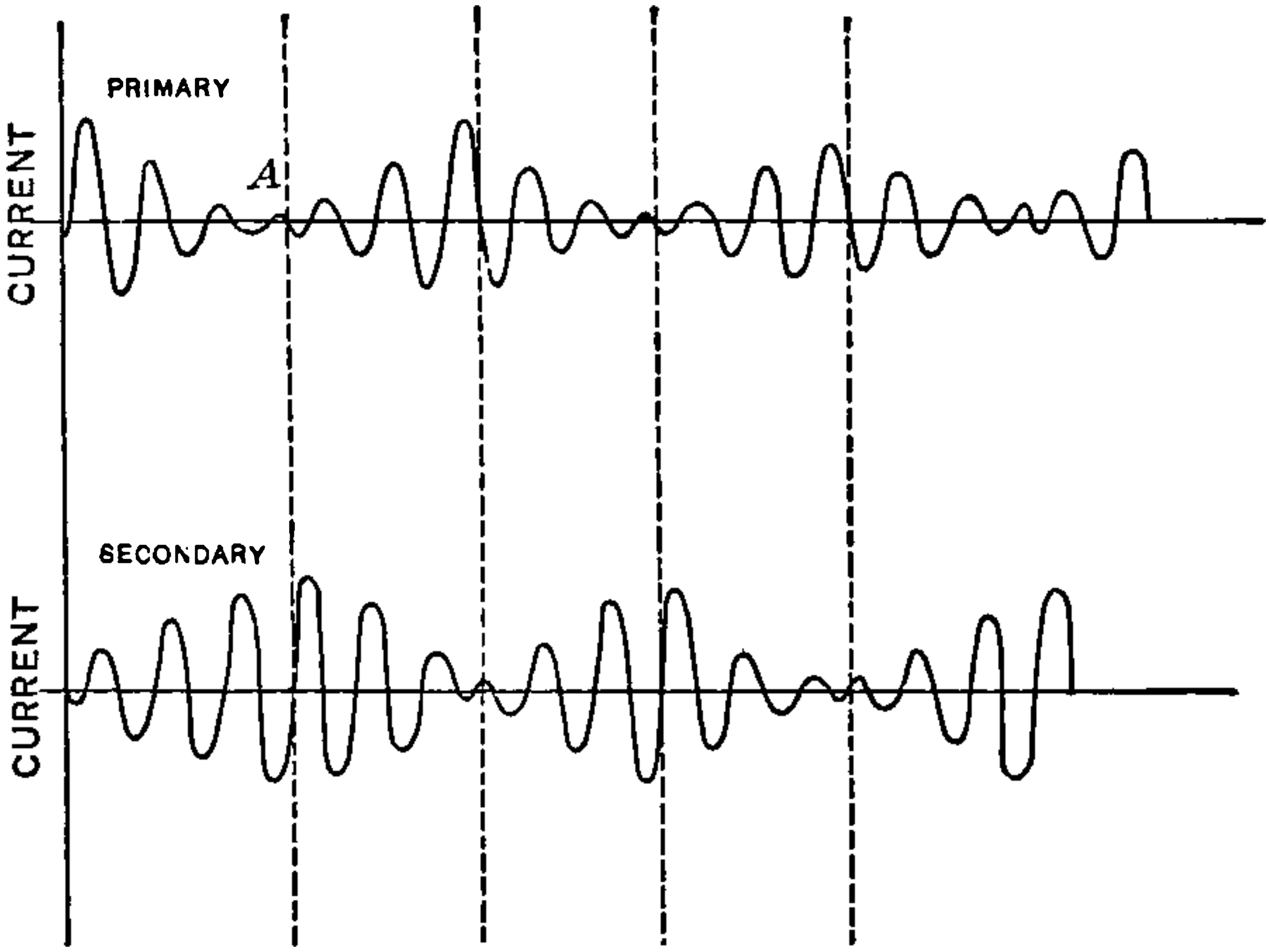
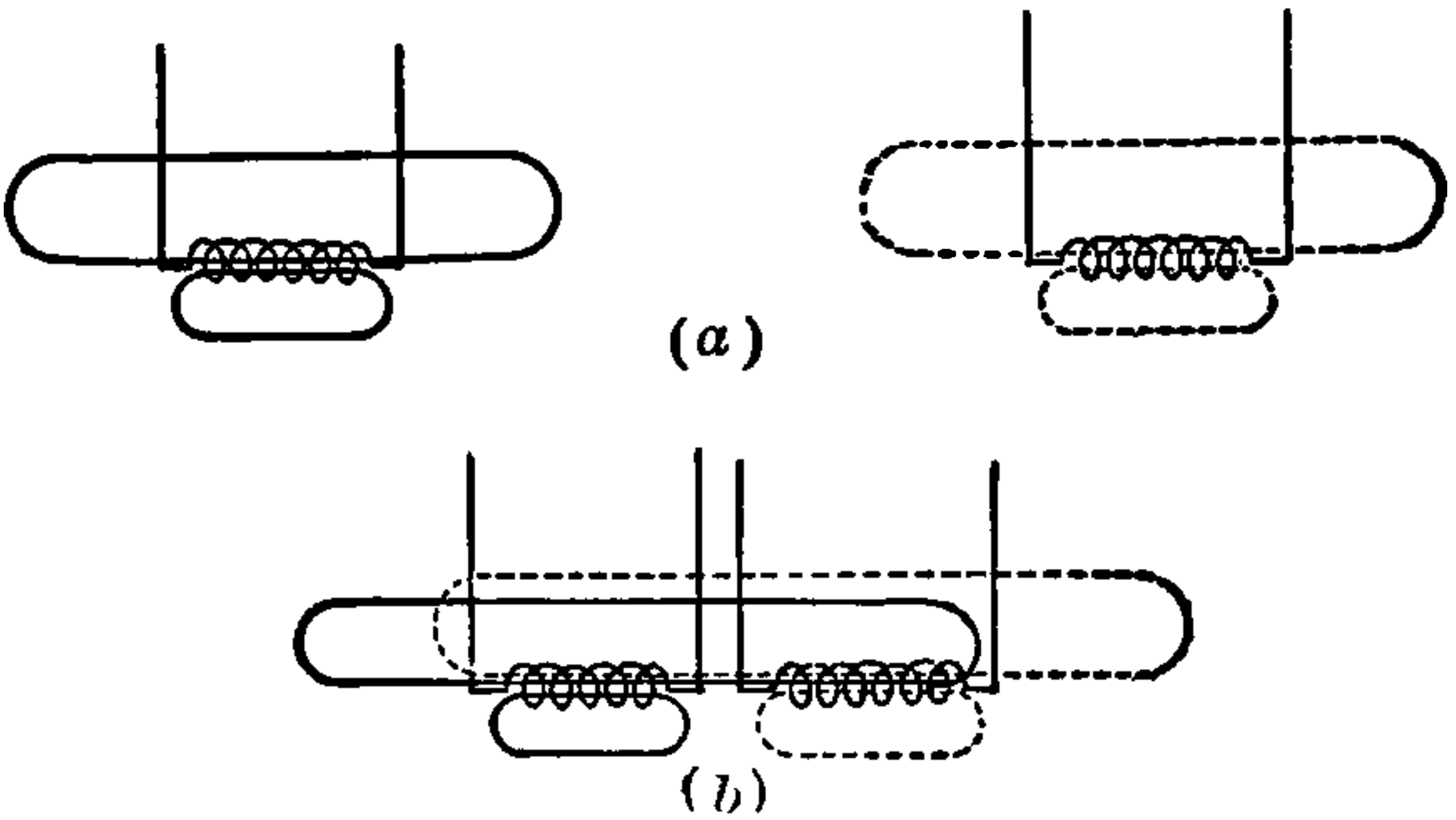


FIG. 405.—Current Curves of Coupled Circuits.

In Fig. 401, circuit *A*, the actual distribution of flux around a coil carrying current is shown. As a matter of convenience, when two circuits are to be inductively coupled, the actual flux may be thought of as being split up into two parts, which together are equivalent to the actual flux. These two fluxes would be as in Fig. 406 (*a*). It is, of course, flux linking with a coil which causes the inductance of the coil, the inductance being numerically equal to $N\Phi/I$, where N is the number of turns in the coil, Φ the flux shown in Fig. 406(a) and I the current which is required flowing through the circuit to cause this flux to be set up. If the coil of Fig. 406(a) is connected in series with another similar coil and the two coils so placed that no flux from one links with the other, the total flux through each coil is unchanged, the inductance of each coil is unchanged, and the total inductance will be found to be simply the arithmetical sum of the inductances of the separate coils. Consider the effects of bringing the coils close together as shown in Fig. 406(b). The flux from the right-hand coil is shown by dotted lines, that from the left-hand coil by solid lines. If the coils are so placed that all of the fluxes are going in the same direction, the total flux through each coil is increased, and the effective inductance of *each* coil is increased by an amount due to the increase of flux through that coil, the total inductance thereby being increased by twice this amount. This added inductance in each coil due to flux from the other coil is known as mutual inductance (symbol M). The total inductance is now (L_a+M)


(a)

(b)

FIG. 406.

each pan suspended by a spring from a fixed point. The weights and springs must be so adjusted that these two devices will oscillate up and down at exactly the same rate, when entirely separate.* The cross beam and center pan shown are made of such light weight that the effect of their weight is negligible. In this system the motion of the weights corresponds to the flow of current in an oscillating circuit, and the forces correspond to the voltages. The weights, due to their kinetic energy, store energy in the same manner that an inductance does when a current flows. The spring aided by the force of gravity stores energy as the condenser does. The coupling between these two oscillating circuits is provided by placing a weight on the center pan, thus corresponding to inductive coupling of electrical circuits. To make this system act as the circuits of Fig. 406(*b*) do, take, say 50 gm. from the left-hand pan and 50 gm. from the right-hand pan each to represent M. Take also 100 gm. from some outside source to represent the $2M$ gained by the coupling. Place this 200 gm. on the center pan. The capacitance of this system, as represented by the springs has not changed, but if all the weights are started moving up or down *simultaneously,* it will be seen that the weight carried by each spring is one-half of the total, or the original weight $+50$ gm. (corresponding to $L+M$). The motion in this case presents the lower frequency at which this system can oscillate. If the left and right-hand weights are started in opposite directions with equal velocity, so that one goes up while the other goes down, the 200 gm. carried in the center will not move. The weight moving with each spring will be the original $-$ 50 gm. (correspond-

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* To simplify the explanation the weights will be taken exactly equal and the springs exactly alike.

ing to $L-M$). The frequency will therefore be higher than the original. This demonstrates that a system such as this can oscillate at *either* of two frequencies separately. If *one* weight is started into motion the beam acting on the central mass as a fulcrum starts the other weight. The first will stop, and then the energy will be re-transferred, just as in the preceding pendulum case. The presence of the two types of motion, corresponding to the two different frequencies, can be seen by watching the system during this action.

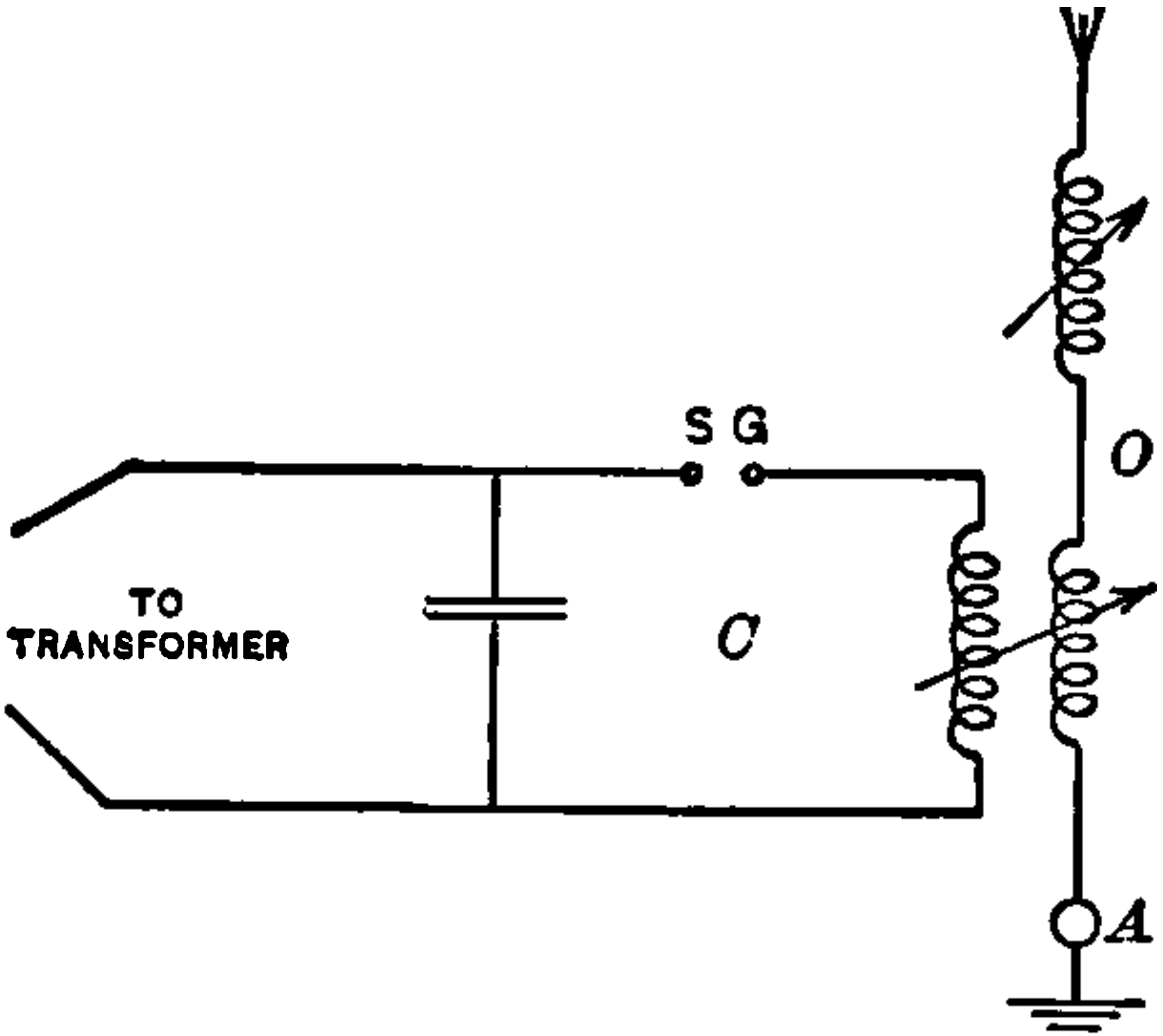

FIG. 408.—Radio Frequency Circuits of a Spark Transmitter.

If the coupled circuits considered are the closed, or oscillating, and the open, or radiating, circuits of a spark transmitting set, as shown in the figure, the effects noted are, for some reasons, very objectionable.

The object in a transmitting set is to radiate as much energy as possible at a fixed wave length. We shall study in detail the effects on energy radiation and wave length of varying the coupling between the closed circuit and the radiating circuit, C and O in the figure. If the hot gases remain in the gap so that the resistance of the gap is low throughout the wave train, the curves previously shown, Fig. 405, apply to these circuits. The decrement of a circuit is a function of the resistance, inductance, and capacitance, and varies directly as the capacitance. Since the capacitance of the closed circuit is much greater than that of the open circuit, its decrement is also much greater. The ohmic resistance of the open circuit is usually very low and the principal source of damping is the loss of energy due to the radiation of electromagnetic waves and loss due to imperfect dielectric. It is readily seen that the closer we couple the circuits *C* and *O* the more energy is transferred to the open circuit, but at the same time energy is more rapidly returned from *O* to *C*, due to flux of *O* reacting on *C*. This results in increased damping of the open circuit which is undesirable. Also that part of the energy returned to the closed circuit which is dissipated in that circuit as heat and light, represents a distinct loss. Most efficient operation is attained when a maximum amount of energy is transferred to the open circuit and dissipated in that circuit as electromagnetic radiation.

The radiation from the open circuit can be studied as follows. Couple circuits *C* and *O* closely and couple loosely to *O* a wave meter equipped with a current-squared meter or wattmeter, or other device whose reading is proportional to the energy in the circuit. Set wave meter to any desired wave length and read current-squared meter. Take several readings above and below the wave length to which the circuits *C* and *O* are tuned. Plot the readings of the wattmeter or current-squared meter as ordinates against the wave-meter setting as abscissæ. The result will be a curve as shown in Fig. 409, called a resonance curve. This curve shows that energy is being radiated principally at two wave

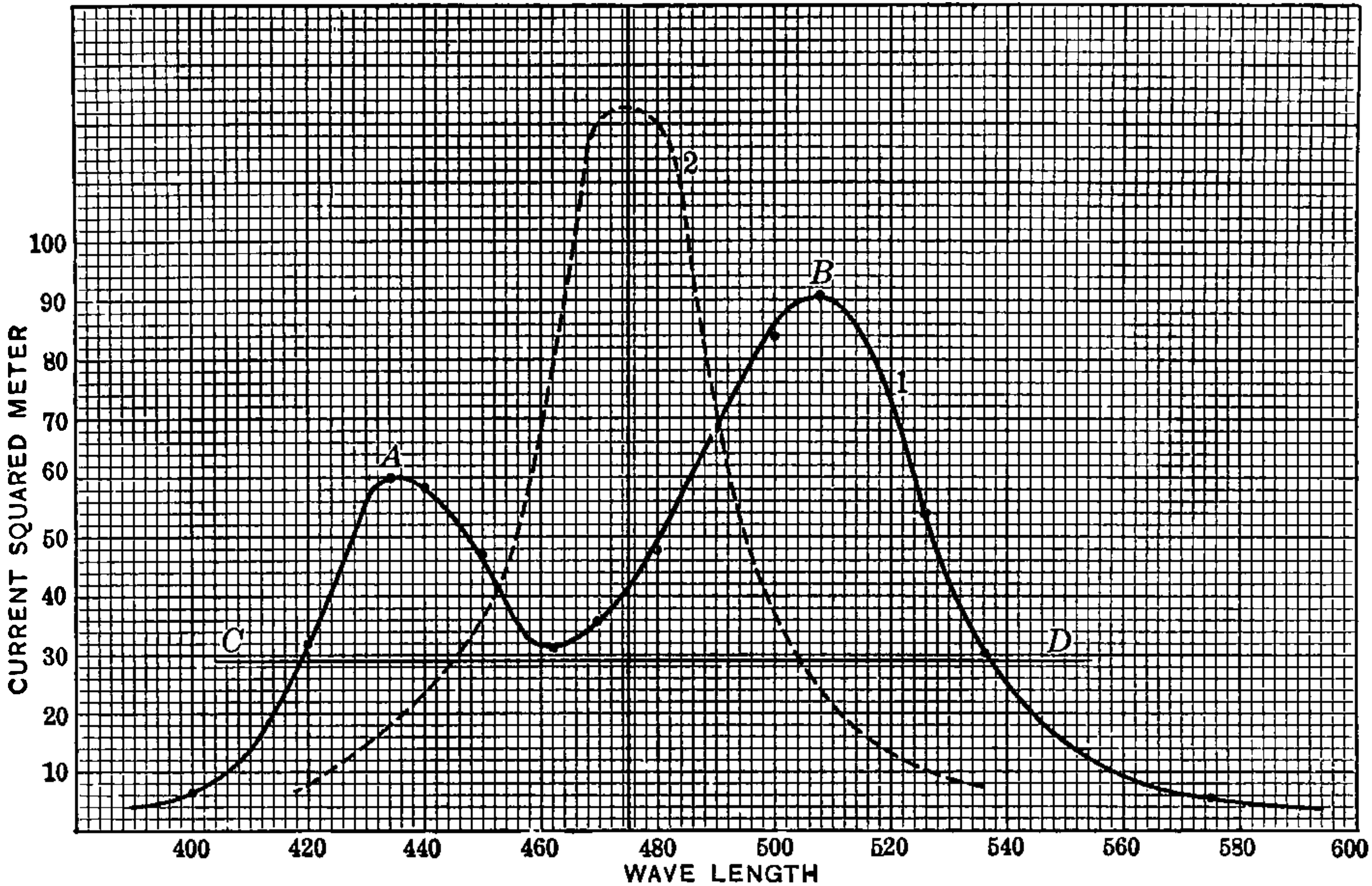

FIG. 409.—Resonance Curve. Experimental Transmitting Set, U. S. Naval Academy. Circuits Adjusted to 475 Meters.

lengths as indicated by the points A and B. The wave meter circuit picks up some energy when adjusted to any wave length between the limits of the curve, but the points A and B are decided maxima. Suppose the height of ordinates of the line CD represents sufficient energy to operate the receiving device of a station. Then that station can read the signals when adjusted to any wave length between 418 and 538 meters. Hence we say a broad wave is being sent out. This condition is desirable when the message is to be received by all stations, as when distress signals are being sent out. However, when the signal is intended for a particular station, tuned to a certain wave length, such a wave has the disadvantage of interfering with all stations tuned to wave lengths slightly different, and is not as easily received by the called station as a pure or sharp wave.

Now suppose we loosen the coupling and measure the radiated wave length as before. The peaks approach each other as the coupling is decreased until with very loose coupling the energy is radiated at a single wave length as shown in curve 2. This wave length will be found to be that to which the two circuits are tuned. Various means have been devised to obtain this pure wave and at the same time use closer coupling, with increased energy transfer. Perhaps the best results have been obtained with the so-called "quenched gap," which will be described in chapter on Spark Transmitting Sets.

Coefficient of Coupling.

The coefficient of coupling is a measure of the interaction between coupled circuits and in inductive coupling is given by the formula $M/\sqrt{L_1L_2}$, where M is the mutual inductance of the circuits and L_1 and L_2 are the inductances of the individual circuits.

CHAPTER V.

VACUUM TUBES.

As has been explained, every metal is believed to contain large numbers of electrons which are free to move about within the metal. As long as the average velocity of these electrons is relatively low (say less than 100 km. per second) any electron which happens to come very close to the surface of the metal will be acted upon by a force exactly similar to the surface tension in a liquid, and will not be able to escape from the metal. If the average velocity of the electrons is increased, some of them will reach velocities high enough to enable them to pass out of the metal. This increase in the average velocity of the electrons is produced by heating the metal, and is accompanied by an escape of electrons which increases very rapidly with the rise in temperature.

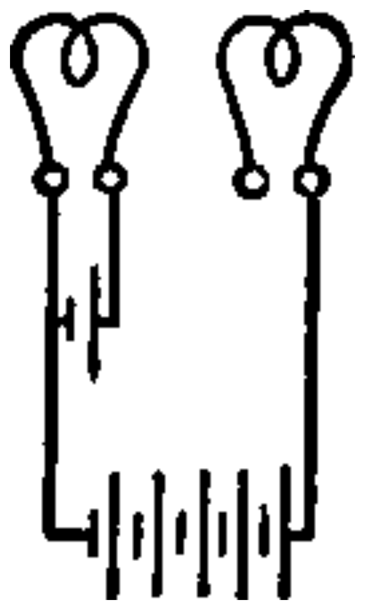

FIG. 501.

Consider an incandescent lamp with two independent filaments. If *one* of the filaments is heated it will give off electrons. Now if a battery is connected, as shown in Fig. 501, so that the cold filament is charged positively it will attract electrons. As electrons are being given off steadily by the hot filament there will be a steady stream of them across the space between the filaments. It is to be noted that as the charges of electricity passing from the hot filament to the cold one are *negative* the current is thought of as passing from the cold filament to the hot one. If the cold filament had been given a negative charge it would repel the electrons given off by the hot filament, and there being no electrons given off by the cold filament there would be no flow of current. As this seems to completely explain the action when the cold filament is negative (if there is only a negligible amount of gas in the tube), the following discussion will be devoted entirely to the action when the

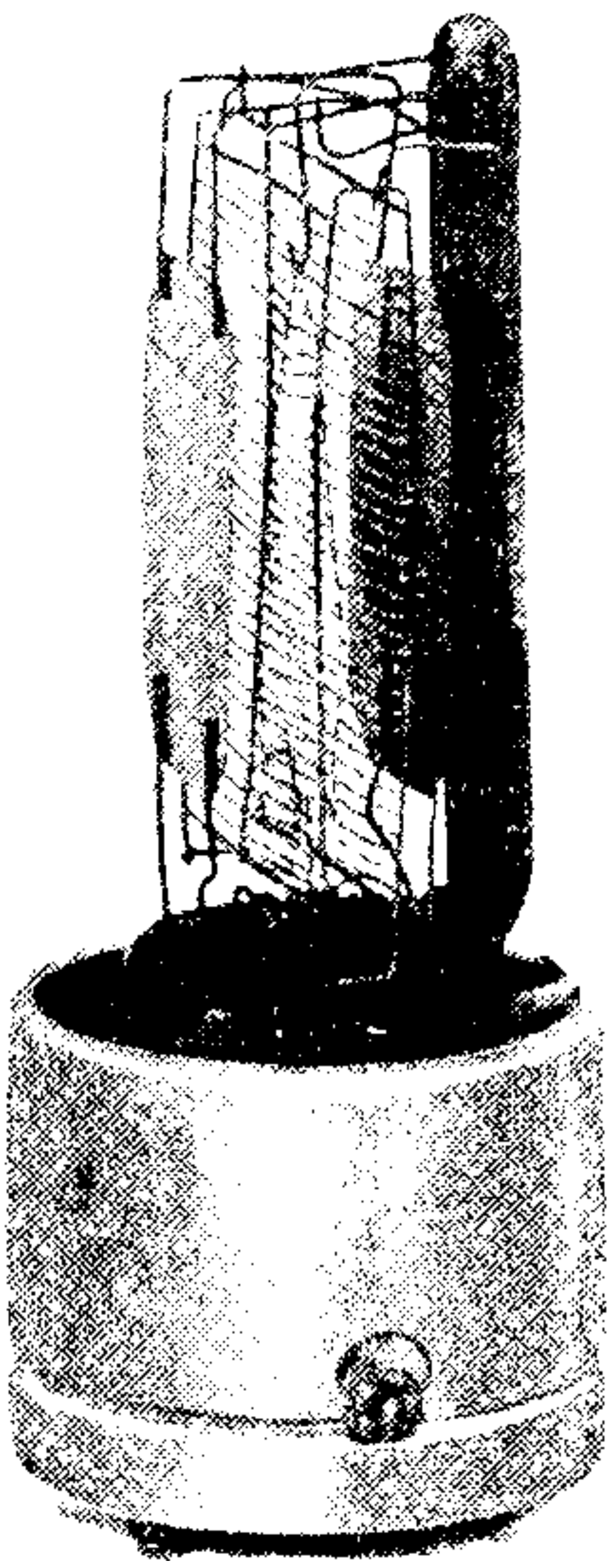

FIG. 501A.—Three-Element Vacuum Tube; Glass Bulb Removed.

action of the other electrons is in all cases a repulsion, as like charges always repel each other. Its direction in the tube depends upon the position of the other electrons, being away from the plate for electrons between the one considered and the plate, and toward the plate for all others. It should be noted that the force on one electron due to the action of the others changes as the electron passes from the filament to the plate. The nearer to the plate it gets, the smaller is the number of electrons ahead of it, and the larger the number behind it. Ordinarily, at some point between the filament and the plate the force acting on the electron to move it toward the plate or filament will be zero. If the initial velocity of the electron carries it beyond this point it will continue toward the plate with a rapidly increasing velocity. If the initial velocity does not carry it beyond this point the forces acting in the tube will carry it back to the filament. The current flowing through this tube will increase with increasing plate voltage until *all* of the electrons given off by the filament go to the plate. After this any further increase in the plate voltage will not increase the current. The change of current in the plate circuit with changing plate voltage is shown in Fig. 502 for two different temperatures of the filament. We see from these that the current is controlled directly only by plate voltage.

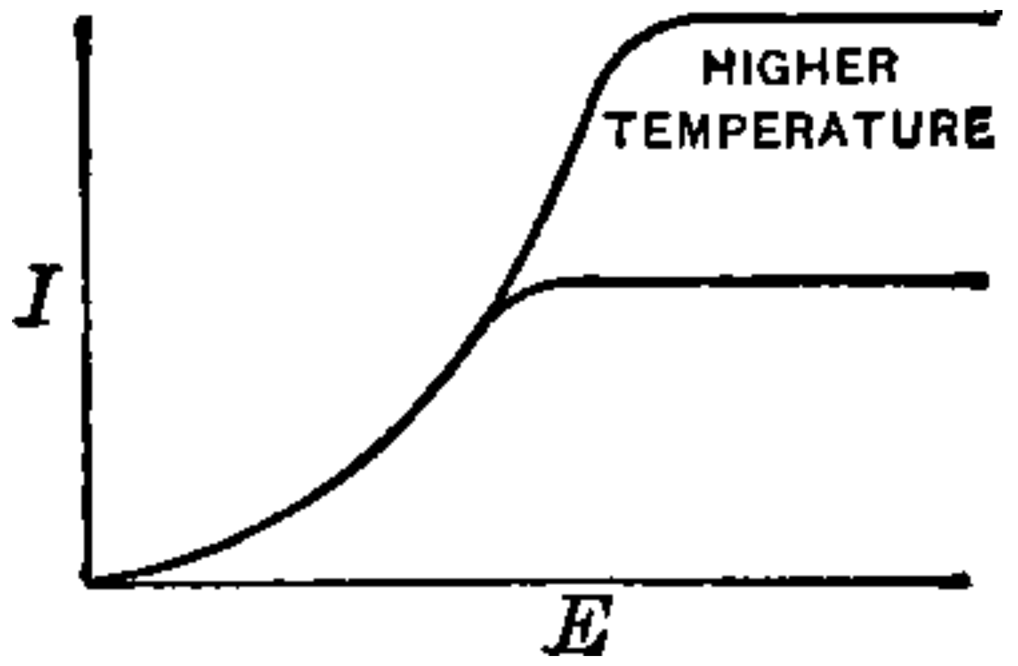

FIG. 502.—Two-Element Vacuum Tube Characteristics.

The tube described above is known as the Fleming Valve, or "two-element vacuum tube." Its check valve action may be utilized at radio frequencies as a detector. However, due to the great superiority of one of its modifications, the simple valve is seldom used for a detector.

The idea of introducing another means of controlling the motion of the electrons in a vacuum tube was originated by DeForest. He introduced a "grid" of conducting material between the plate and the filament, thus producing the "three-element vacuum tube," or "audion." The introduction of this conducting grid makes it possible to control the motion of the electrons in the tube independently of the plate voltage. It will readily be seen that charging this grid negatively will act on the electrons as they are given off by the filament and will drive back to the filament some of those which would otherwise have gone to the plate. This is the direct cause of a decrease in the plate current. Similarly, it will be seen that a positive charge on the grid will aid the electrons in getting away from the filament. This will cause some electrons to pass to the plate which would otherwise have returned to the filament. This in turn is the direct cause of an increase in the plate current. It is to be particularly noticed here that although the grid is positive and should apparently draw the electrons direct to itself, only a small percentage of the electrons go to the grid, while the rest pass on to the plate, because normally the plate voltage is *much* higher than the highest voltage reached by the grid. The few electrons which go to the grid when it is positive constitute a current flowing from grid to filament. The circuit outside of the tube, connecting the filament to the grid is known as the grid circuit. Due to the fact that the grid is always placed closer to the filament than the plate is, a change in the voltage applied to the grid will have more effect on the motion of the electrons in the neighborhood of the filament than an equal change in the plate voltage would have. This means that a change in the voltage applied to the *grid* will have more effect on the *plate* current than an equal change in voltage applied to the plate would have. Stated in another way, it may be said that a small change in the plate current may be produced in either one of two ways, either by changing the plate voltage or by changing the grid voltage. To produce the change in plate current by means of a change in plate voltage will require a larger change in voltage than to produce the same change by means of a variation of the grid voltage. Usually it will require from five to forty times as much change in plate voltage as in grid voltage to produce the same effect on plate current. This ratio is a constant which depends principally upon the construction of the bulb. It may be measured readily by means of the connections shown in Fig. 503. Using values of voltage suitable for the particular tube, the plate current is first changed somewhat by a definite variation of the plate voltage E_B. The plate current I_B is then returned to its origi-

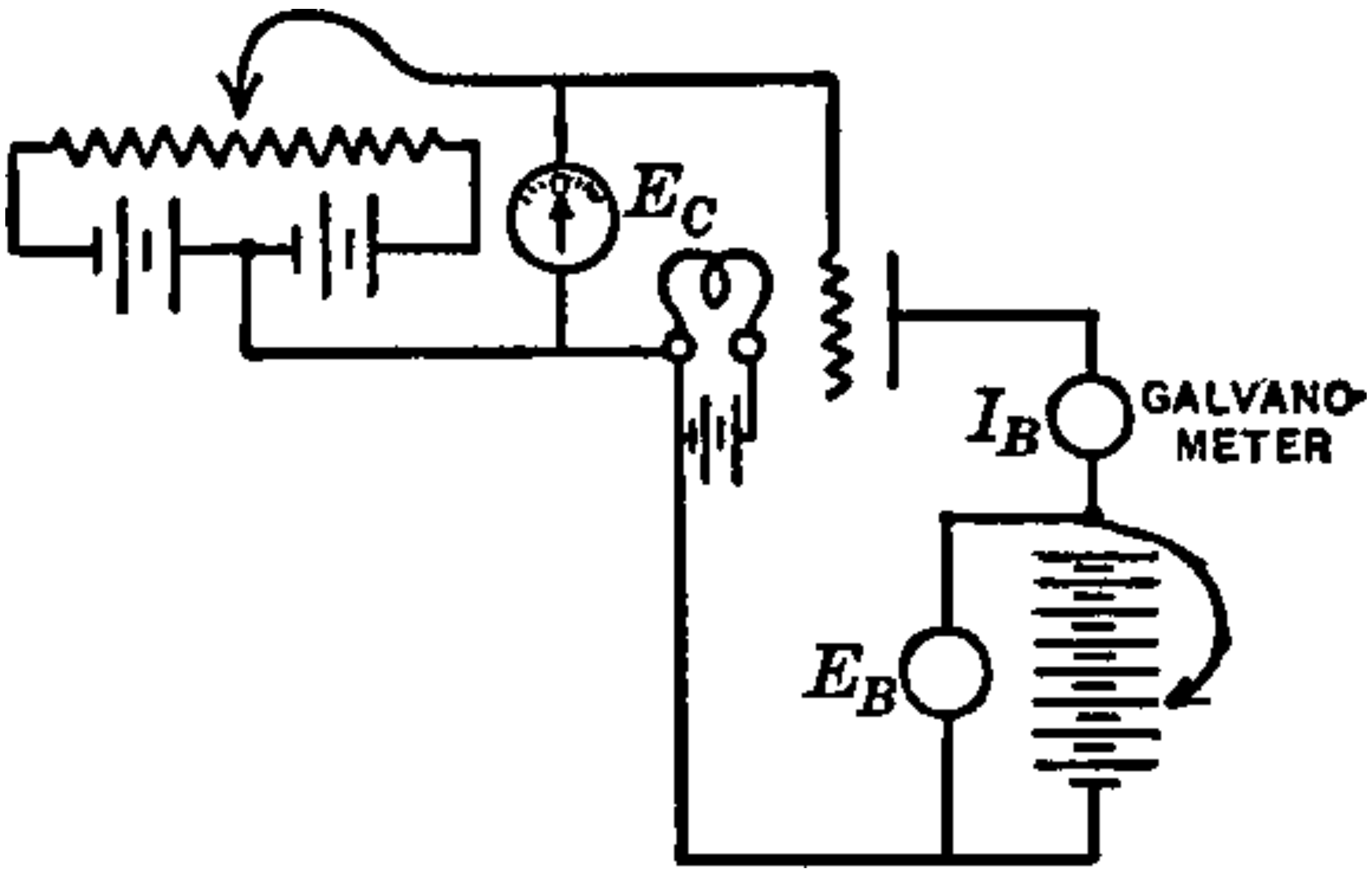

FIG. 503.

nal value by means of an opposite change in the grid voltage E_C. It will be seen that the current need not be known in value as long as a means is provided to enable one to return to the original value. For this reason a galvanometer may be used as a current measuring device without knowing what value of current is indicated by the scale readings. The change in plate voltage divided by the change in grid voltage in the above case is a measure of the effectiveness of the control of the electrons by the grid.* Typical characteristic curves showing the variation of plate current and of grid current with variations of *grid* voltage are shown in Fig. 504 for two widely different values of plate voltage.

The plate current is the current which flows from the plate to the filament through the tube. The grid current is the current which flows from the grid to the filament through the tube. It is to be understood that while taking one of these curves the plate voltage is kept constant at the value marked on the curve. It will be seen that in the case of the plate current an increase in the plate voltage shifts the curve over to the left without changing its shape appreciably. (This holds only over a certain range, and is not even approximately true on low voltages.) This shift causes any particular value of plate current to correspond to a lower value of grid voltage than before. In the case of the grid current there is very little change in the point at

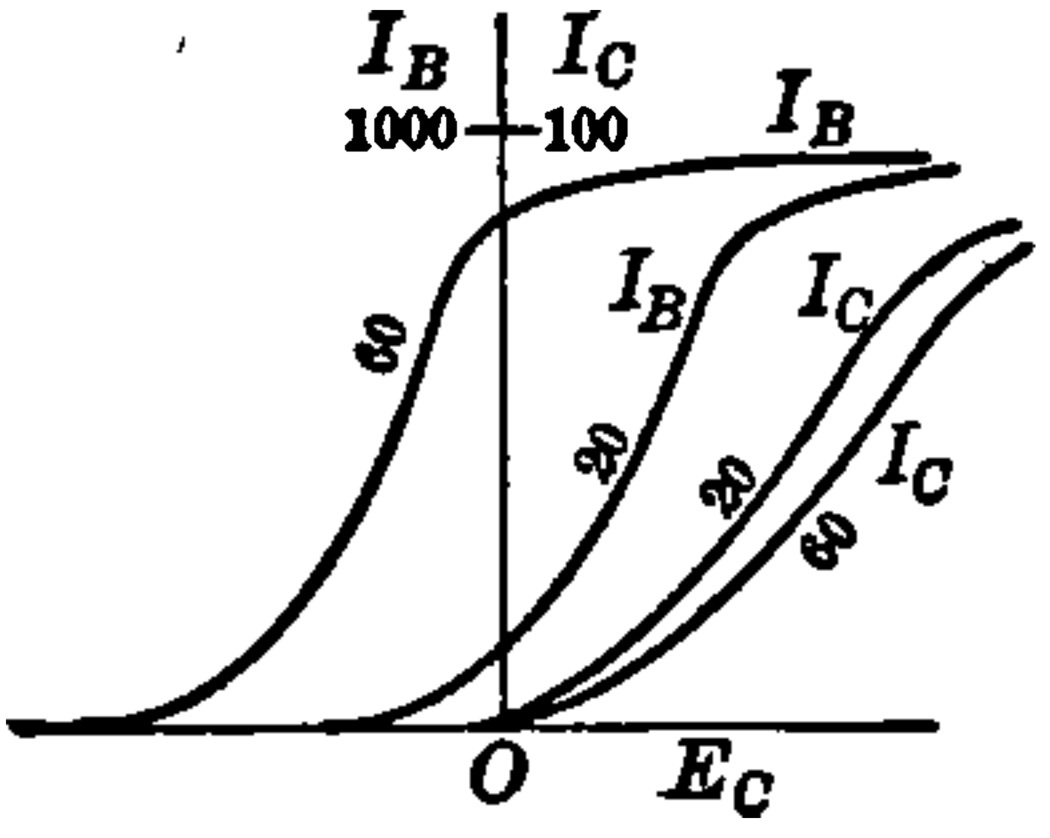

FIG. 504.

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*This ratio, denoted by μ_0, is also the maximum value of voltage amplification obtainable from the tube.

which the curve starts from zero, but for higher plate voltages the grid current is smaller, due to fewer electrons escaping the increased attraction of the plate. The values of grid voltage shown above are measured from the negative terminal of the filament.

In order to picture the action of the tube in terms of the elementary ideas of Ohm's law, it is convenient to consider the resistance of the path through the tube from plate to filament. It is seen from the preceding explanations and from the curves of Fig. 504 that with a constant plate voltage the resistance of the tube from plate to filament varies as the grid voltage varies, being nearly infinite for negative grid voltages up to a certain point. From here on, as plus values of grid voltage are approached the resistance drops, until it finally approaches a relatively small value. This variation of the internal resistance of the tube may then be thought of as the feature which controls the flow of the plate current. The controlling action of the grid may also be thought of as simply that of a valve in the power line from the high voltage battery in the plate circuit. The valve closes gradually as negative voltages are applied, and opens with positive voltages. A very small amount of power is sufficient to work this valve. The power controlled *by* the valve may be many times as great as the power necessary to operate the valve. Also, if the action of the tube is limited to that portion of the I_B curve (see Fig. 504) that is approximately straight, the current controlled by the valve varies directly as the voltage applied to the grid.

From the preceding paragraph it follows that the vacuum tube may be used as a relay. A simple circuit for use in this manner is shown in Fig. 505. If a varying voltage from *any* source is applied between the grid and filament, the variations which take place in the plate current will be similar to the applied voltage. Such a case is presented in Fig. 506. In this figure E_C is the voltage applied between the grid and filament, I_B is the corresponding flow of current in the plate circuit, and I_L is the current flowing from the secondary of the transformer to the load. I_L is due, of course, to the E. M. F. induced in the secondary of the transformer by the variations of flux through this secondary when the primary current varies. It is to be noticed that although, due to the nature of the tube, I_B varies but never reverses, I_L is an alternating current similar to the voltage applied to the grid. As ordinarily operated, the energy available from the variations in the plate current is many times as great as the energy necessary to produce the variations in the grid voltage. When used to utilize this reproduction of a current with increased energy in the output, the tube is called an amplifier. The small amount of energy that is used to produce the voltage applied to the grid is used up in the tube and the circuits connected with it. The energy which is available in the plate circuit is controlled *by* the grid but comes *entirely* from the high voltage battery in the plate circuit.

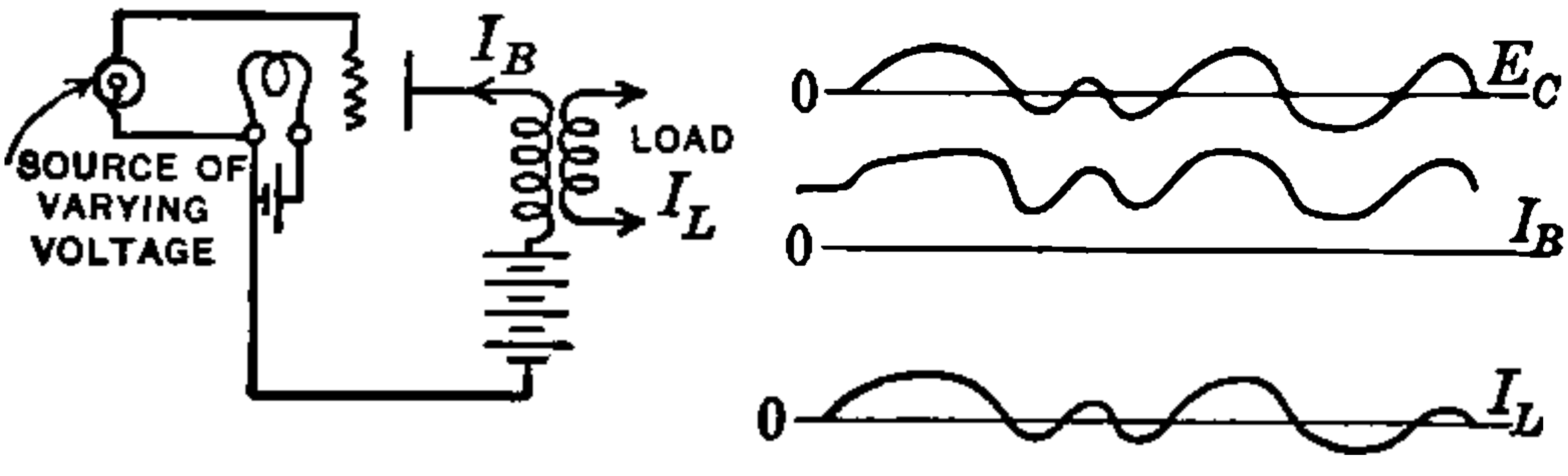

FIG. 506.

This control of a relatively large amount of energy by a small amount of energy is made use of in receiving apparatus when the signal to be received is too weak to produce reasonable signals in the telephones. In this case the energy which would otherwise go to produce a sound in the telephones is used to vary the grid voltage of a three-element vacuum tube. The changes in the grid voltage control a relatively large amount of energy from the high voltage battery in the plate circuit of the tube, and a telephone placed in this plate circuit will have signals reproduced in it appreciably louder than the signals in a telephone connected directly to the receiving apparatus. If the signal is not loud enough after amplification by one tube, the output of the first amplifier tube may be used to vary the grid voltage of a second three-element vacuum tube, the output of the second tube may be used to vary the grid voltage of a third, and so on. There are practical limits to this which will be discussed later.

The simplest way to transfer the energy from a detector to an amplifier tube, or from one amplifier tube to another, is probably by means of a transformer. The primary of this transformer carries the current from the source of the weak signal. The changes in this current cause changes in the flux through the winding, and this changing flux cutting the secondary winding produces a voltage in it similar to the changes in the primary. As the secondary winding has several times as many turns as the primary, the voltage produced in it is larger than the primary change of voltage. This larger voltage is applied directly between the grid and filament of the amplifier tube to control its output.

Consider the circuit of Fig. 508 where *AC* is an alternating current generator which is supplying power to the input circuit (between grid and filament) of an amplifying tube. Assume that the power supplied to the tube is 10 microwatts. The output available at the secondary of the transformer *T* might be 1000 microwatts. Assuming this to be the case, apply to the secondary of the transformer a load which will take 990 microwatts. Now it should be evident that if it is possible to take the 10 microwatts that are left over and supply them to the input circuit of the tube in place of the generator, the generator may be removed, and the tube will continue to generate alternating current without the assistance of an outside alternator. In order to do this it is found that with all ordinary apparatus the following requirements must be met:

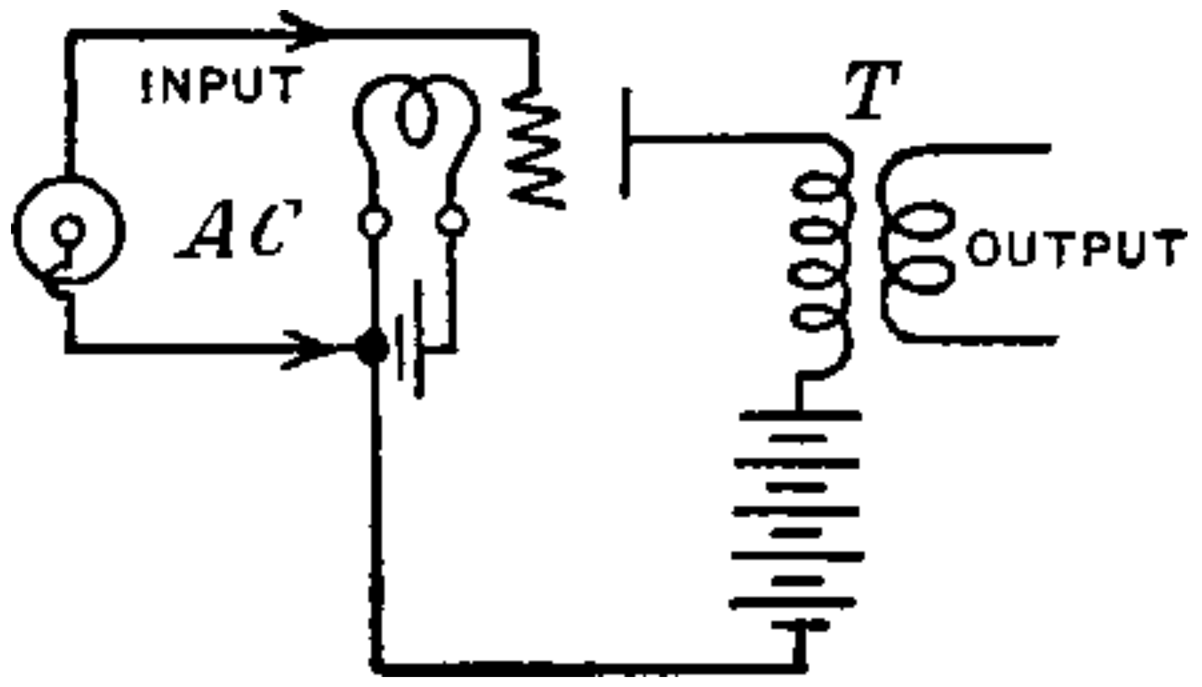

FIG. 508.

(1) The output of the tube must be greater than the input, that is, the tube must be an amplifier.

(2) There must be an oscillating circuit. (This controls the frequency of the current generated and the phase of the voltage applied to the grid.)

(3) Variations occurring in the plate current must transfer part of their energy to the oscillating circuit.

(4) Oscillations occurring in the oscillating circuit must transfer part of their energy to the input circuit of the tube, with the proper phase relation, in such a way as to maintain the variations in the plate current.

NOTE.—A valuable check on whether a circuit should satisfy the last part of requirement (4) is the fact that if the circuit is correctly arranged, an oscillation occurring in the oscillating circuit will tend to make the voltage of the grid negative with respect to the filament at the time that it tends to make the

The number of combinations differing at least slightly from one another, that may be used to satisfy requirements (2), (3), and (4) are almost unlimited in number. It is found, however, that the elementary means of satisfying the *separate* requirements are very few in number, so that an understanding of this small number of possibilities will make it possible to trace out the action of more complicated circuits.

As has already been explained, the elementary oscillating circuit consists of inductance and capacitance in series. The inductance may be made up of several parts connected together, and the capacitance may be made up of several condensers, these parts being in series, in parallel, or in any other combination. Another simple variation of the oscillating circuit is of the type shown in Fig. 509. Here inductance and capacitance alternate instead of being put all together. They still form a simple series circuit, and form but a slight modification of the simplest form of oscillating circuit. In order to satisfy condition (2) the oscillating circuit need not be one of the above types. It may consist of two or more simple oscillating circuits coupled to each other by any one of the systems of coupling explained in Chapter IV. In the case of several circuits coupled together, it has been explained that more than one frequency of oscillation may appear. Ordinarily *only one* frequency will be generated. This will be the one which tends to transfer the greatest per cent of the output back to the input with a phase relation such as to maintain the output.

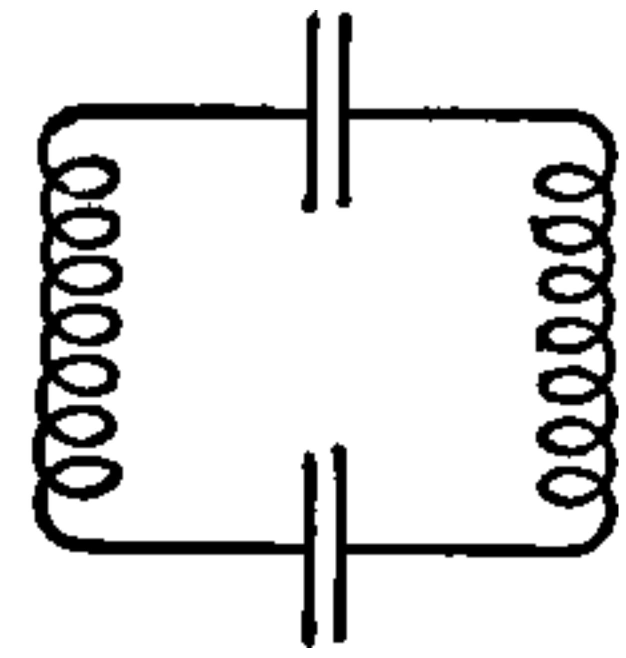

FIG. 509.

Three simple means of satisfying requirement (3) will be considered. The first, Fig. 510A, shows the oscillating circuit connected directly into the plate circuit, so that all of the plate current passes through the oscillating circuit. Fig. 510B differs from 510A only in that the direct current component of the plate current does not pass through the oscillating circuit. The choke coil permits the passage of the direct current but presents a very high impedance to the oscillations, so that the oscillations pass through the oscillating circuit on their way to the filament. Condenser *C* is used to prevent a short-circuit of the *B* battery. Fig. 510C shows no direct connection between the plate circuit and the oscillating circuit, the transfer of energy taking place entirely by transformer action, due to the mutual inductance of the coils.

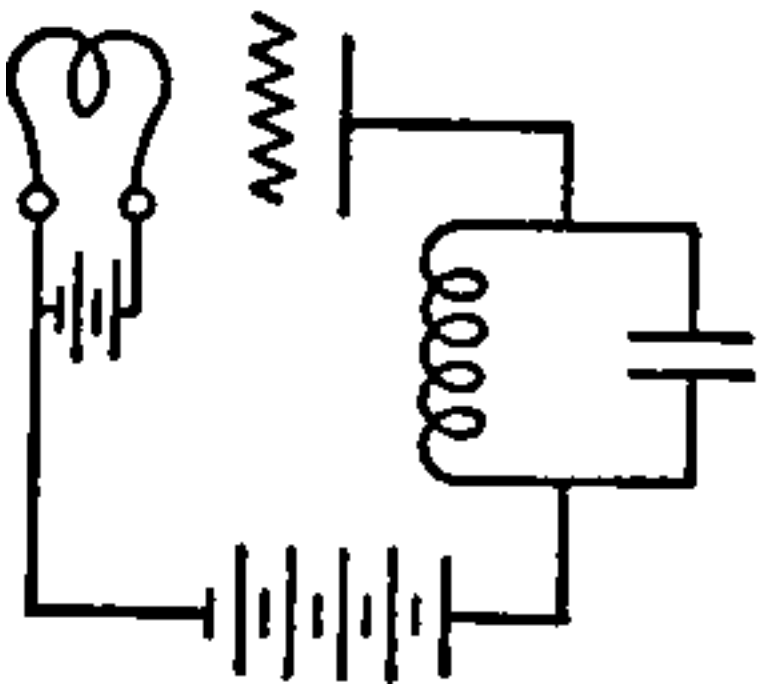

Fig. 510A. Method (3a).

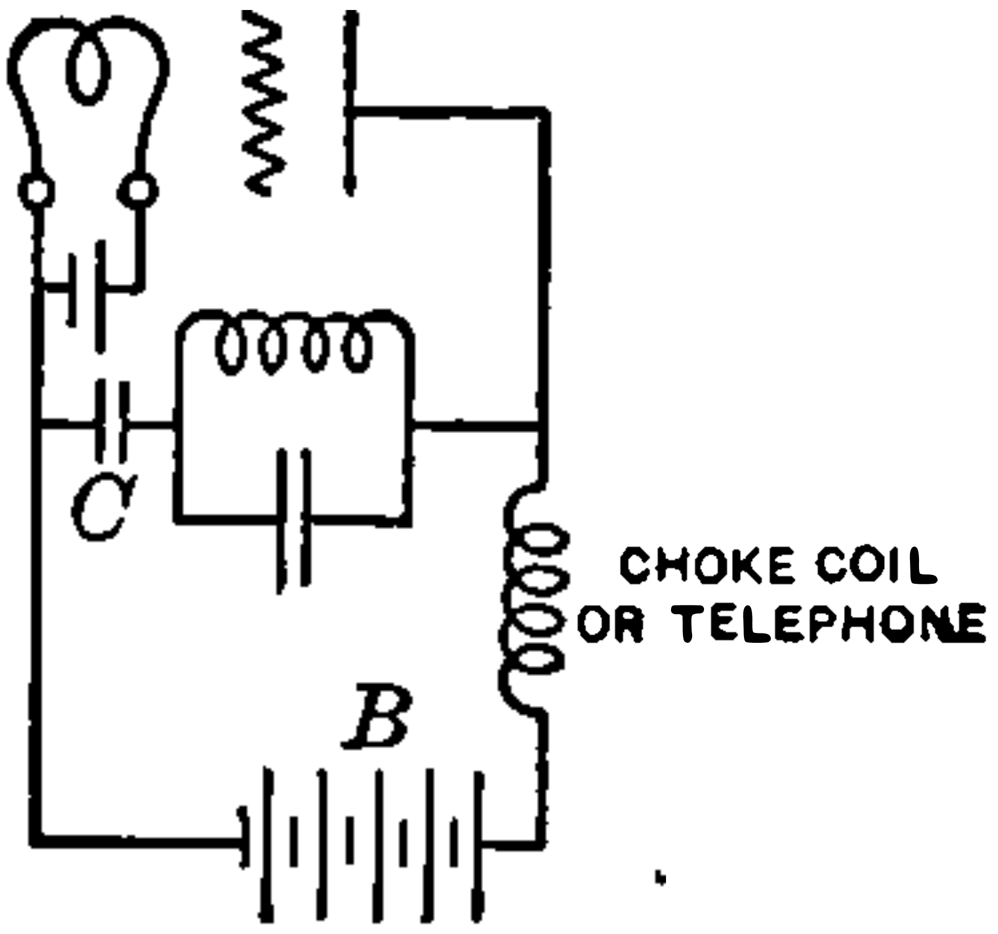

Fig. 510B. Method (3b).

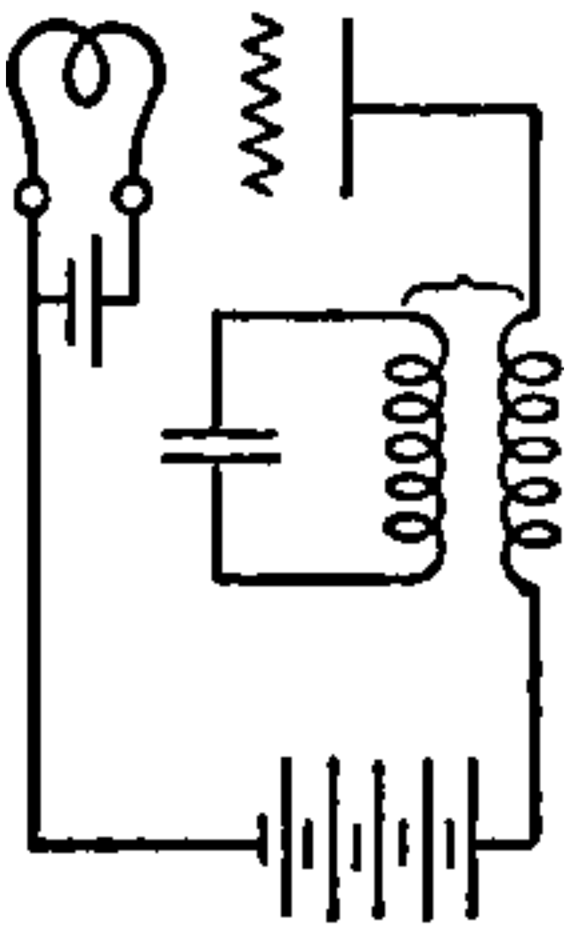

Fig. 510C. Method (3c).

Neglecting the direct current component of the grid current, to satisfy requirement (4) we have the two arrangements shown in Figs. 511A and 511B. Fig. 511A shows the case of direct connection of the oscillating circuit to the grid. This results in a voltage being applied to the grid equal to the voltage produced in the oscillating circuit by the oscillations. Fig. 511B shows the oscillating circuit supplying energy to the input circuit of the tube by transformer action.

It may be seen by referring to the characteristic curves of the three-element vacuum tube (see Fig. 504) that whenever the grid becomes positive with respect to the filament a current flows in the grid circuit. This current consists of electrons, which are attracted to the grid whenever it is positive. If a condenser is placed in series with the grid circuit, these electrons which are attracted to the grid will be unable to leave the grid and will therefore form a negative charge on the grid. Frequently, in a vacuum tube generating circuit, the accumulation of electrons on the grid will produce a negative charge on the grid great enough to practically stop the plate current. This, in turn, will stop the generating action of the circuit, for if there is no input there can be no output. In this case it becomes necessary to provide a path by which the electrons may escape from the grid. This path may be any sort of an impedance which will pass direct current and offer high impedance to the frequency being generated. It consists frequently of a pure resistance of high value. This path is known as a "grid leak." Leakage which is unavoidably present * between the grid and filament assists the action

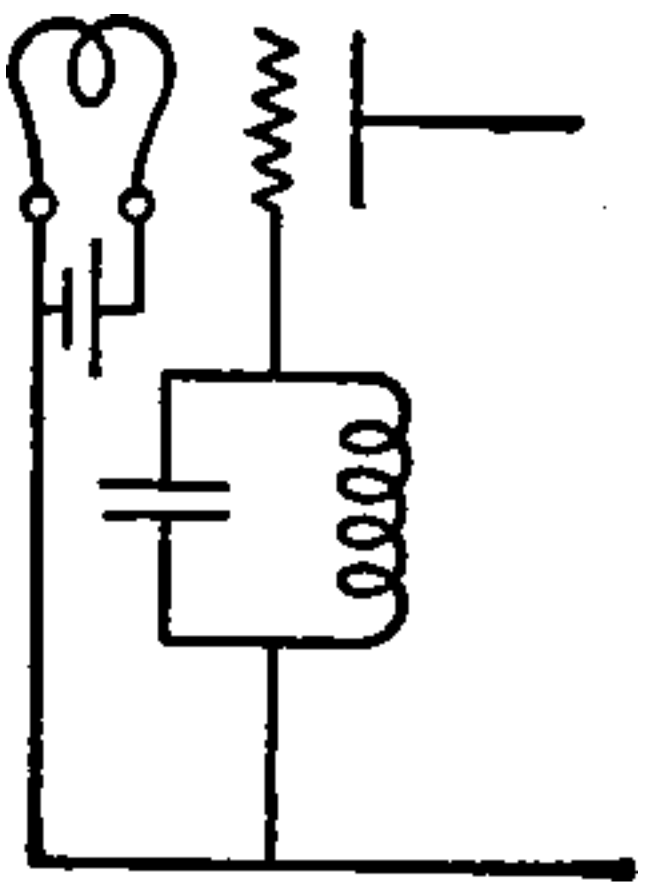

FIG. 511A.
Method (4a).

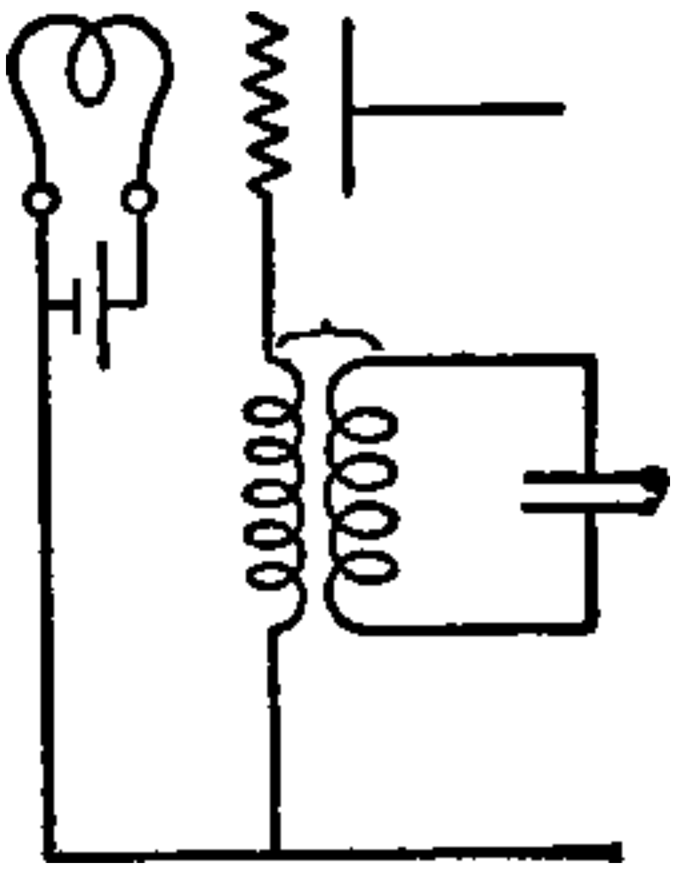

FIG. 511B.
Method (4b).

* Some electrons will be carried from the grid to the filament through the tube by the molecules of gas which are left in the tube, due to the impossibility of obtaining an absolutely perfect vacuum.

of the grid leak, and sometimes makes the use of a grid leak, as a separate piece of apparatus, unnecessary.

A few typical combinations will serve to show the application of the preceding to actual generating circuits. Fig. 512 shows a combination of (3c) and (4a). Fig. 513 shows

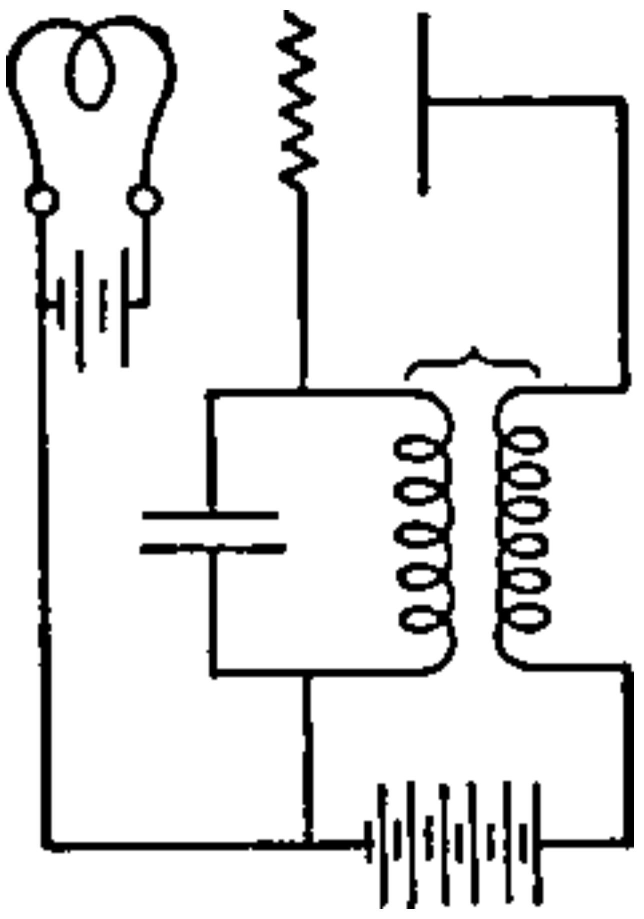

FIG. 512.

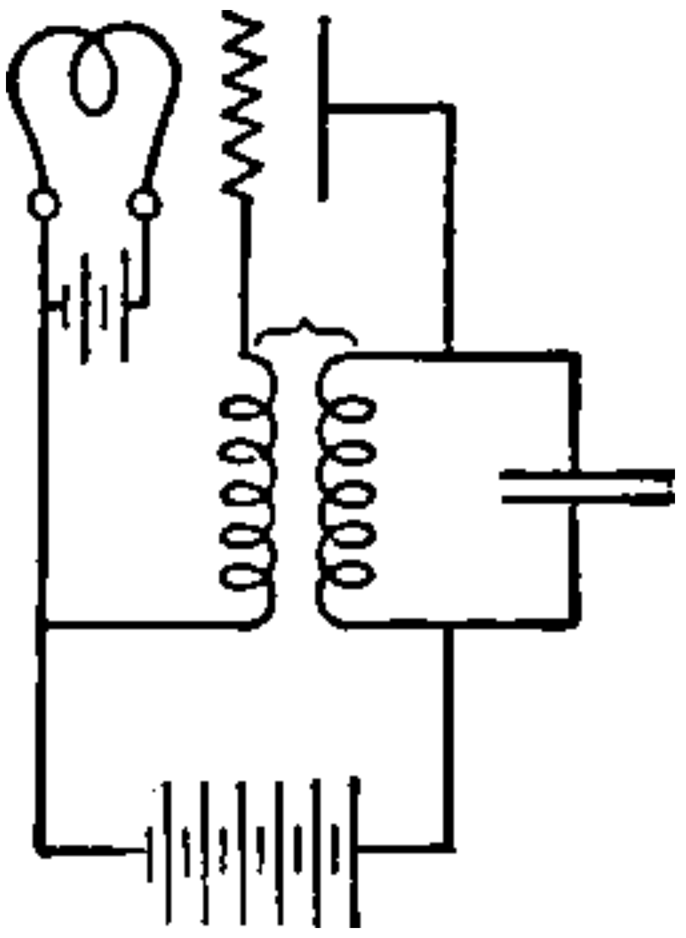

FIG. 513.

a similar combination of (3a) and (4b). These two are so readily seen that their make-up does not require explanation. Fig. 514 shows a combination of (3b) and (4a). In this case it becomes essential to use a grid condenser C_g to keep the high voltage D. C. away from the grid. The condenser C_1 completes the grid to filament circuit of (4a). It is seen that there cannot be a metallic connection at this point, as this would cause a short-circuit of the B battery. It should be noticed that the condenser C_1 at this point is by-passing part of the oscillations around the oscillating circuit so that if it is made large the oscillations produced in the oscillating circuit will not be strong enough to maintain the generating action. If the capacitance at C_1 becomes very small it practically disconnects the grid from the fila-

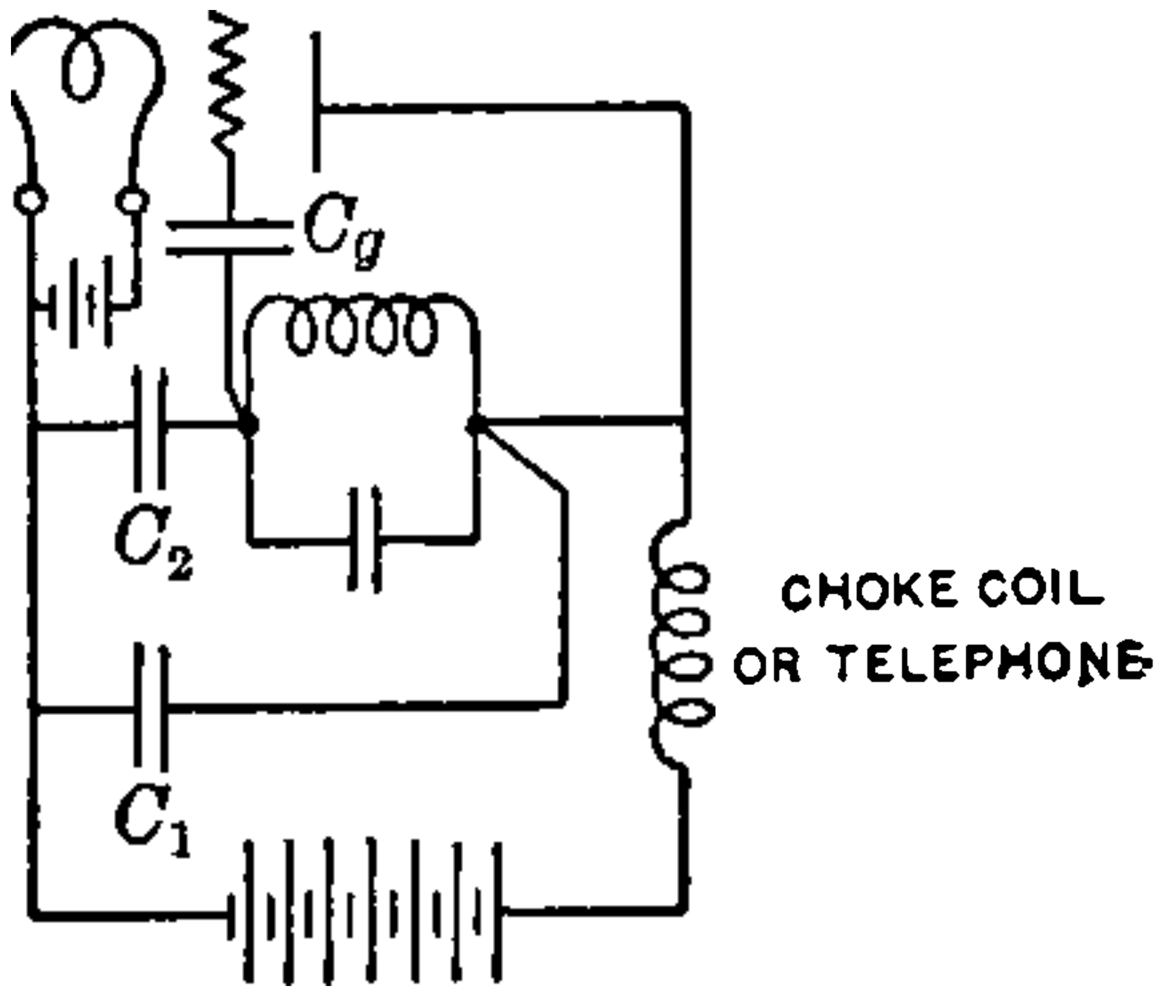

FIG. 514.

ment. If the capacitance at C_2 is made large it will interfere with the action of the circuit by preventing the voltage of the grid from becoming appreciably different from that of the filament. If C_2 is made very small it tends to stop the generating action of the circuit by not permitting the transfer of energy from the plate circuit to the oscillating circuit. Due to the transfer of the energy from one part of the circuit to another through condensers, this circuit may be said to have capacitive coupling. It is probably well to point out here that the capacitance at C_1 and at C_2 is *not* all due to the condensers located at those points. The capacitances between the elements, inside the tube, and that between the connecting wires, outside the tube, frequently are *not* negligible. If the decrement of the oscillating circuit in the preceding circuit is low (that is to say, if the power losses in it are relatively small) the circuit of Fig. 514 will have sufficient capacitance at C_1 and C_2 to generate without having condensers placed at these points. If only the condenser C_2 is omitted, the circuit is DeForest's "Ultraudion" circuit. Fig. 515 shows a combination of (3a) and (4a), both slightly modified from their original form. In this case the inductance of the oscillating circuit is split into two parts as is frequently found convenient. There is direct connection of the plate circuit to one of these parts, and direct connection of the grid circuit to the other.* The capacitance C may be only that between the elements of the tube

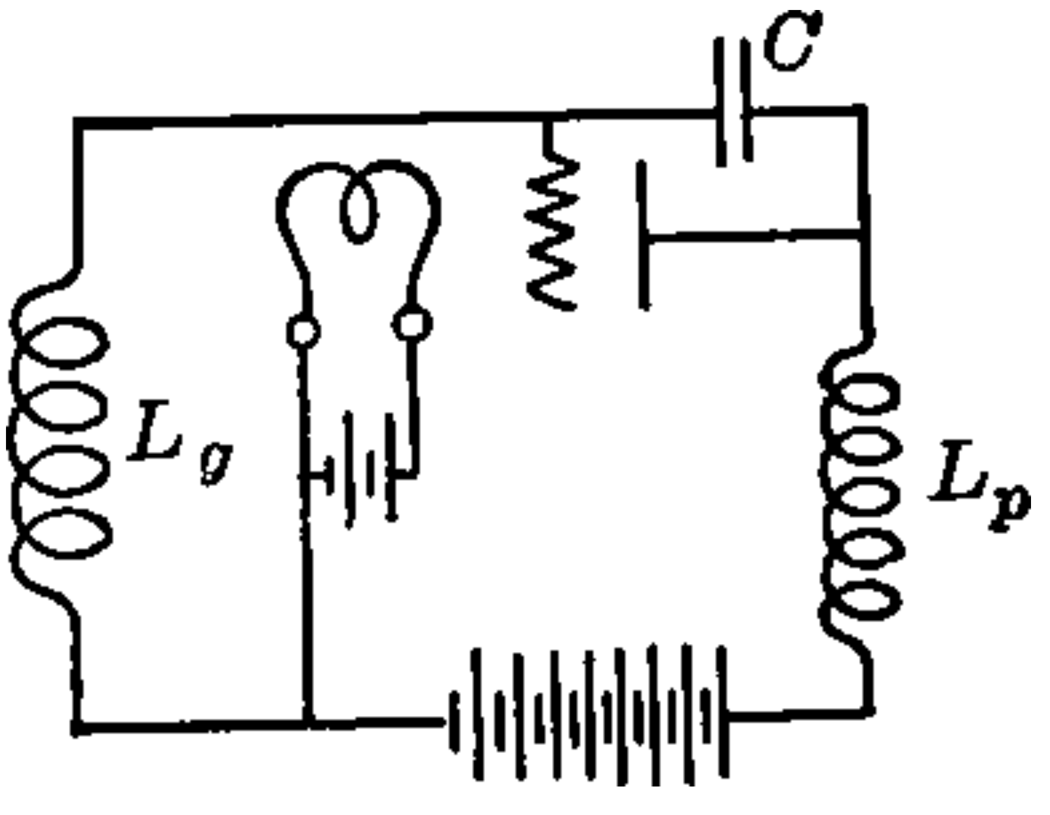

FIG. 515.

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* This circuit places the B battery in the oscillating circuit. The effects of the resistance of this battery may to a large extent be avoided by shunting the radio frequency current around the battery, through a condenser of several microfarads capacitance.

and connections to them. Such a circuit as this latter is found in some amplifiers. In this case the constants of the circuit may be such as to give rise to audio frequency. If the circuit acts as a generator when intended for use as an amplifier, it becomes useless as an amplifier, due to the loud "howl" in the telephones. The plate circuit inductance in this case may be that of the telephones themselves. This circuit may also be thought of as having capacitive coupling due to the fact that energy applied to L_p passes to L_g through C.

later arrangement oscillations are produced in the closed, or spark, circuit, and the antenna is caused to oscillate, with the same, or approximately the same, frequency, by inductive connection. This spark circuit, as previously described in Chapter III, consists of condenser, inductance and spark gap. It is well for the student to bear in mind that the spark gap is not an essential part of an oscillating circuit. Its purpose as used here is to prevent any flow of current other than into the condenser until the condenser has been charged to the desired potential. Practically all naval installations use A. C. to charge the condenser, but D. C. may be used, and a brief description of a set of this kind, as used by the Marconi Company in transatlantic work, will be given later. "Tone" transmission, that is, transmission with a fixed and regular number of wave trains per second is more easily obtained with A. C. than with D. C. supply.

Fig. 601 is a line diagram of a modern spark transmitting set using an alternating current power supply.

The A. C. generator, *G*, is usually a 500-cycle, 110 to 300-volt machine, driven by A. C. or D. C. motor or by turbine. The reason for using 500 cycles will presently be shown.

B is an iron cored inductance used as a reactance regulator, to regulate the power supplied by the generator.

P S is the power transformer, iron cored, either open or closed core type, with primary winding of few turns of heavy wire and secondary of many turns of fine wire, made up in sections. The ratio of primary to secondary voltage is 110 volts to 30,000 volts, or greater.

The condenser, *C*, consists of Leyden jars in series—parallel arrangement; or, in the latest sets, of a mica condenser of Dubilier or similar design.

S G is the spark gap, open, rotary or quenched type. The relative advantages of the different types will be studied.

L and *P′* are spark circuit inductances.

S′ and *L′* are antenna circuit inductances. All inductances in the oscillating circuits are air cored and variable. They may be wound on cylindrical frames or in the shape of expanding spirals. In this latter form they are called "pan cake" coils.

P′ and *S′* form the oscillation transformer, the inductive connection between the closed oscillating circuit and the antenna circuit.

A is a hot-wire ammeter connected in the ground lead of the antenna.

K is the sending key placed in the low voltage circuit.

The circuits to be considered are as follows:

> Primary power circuit, consisting of the armature of the generator, reactance regulator, sending key, primary of the power transformer, and the necessary leads.
>
> Secondary power circuit, consisting of the secondary winding of the power transformer, the condenser and leads.
>
> Spark circuit, or closed oscillating circuit, made up of the condenser, spark gap, two or more inductance coils in series, with leads, made of braided wire of low high-frequency resistance, and as short as possible.
>
> Antenna circuit, consisting of the antenna, loading coil, *L′*, coupling coil, *S′*, hot-wire ammeter and ground connection.

Briefly, the operation of the set is as follows: When sending key *K* is closed the generator sends low voltage current, at 500 cycles, to the power transformer. The condenser, which is connected across the secondary of this transformer, has impressed upon it a voltage depending upon the ratio of turns of primary and secondary windings. In modern naval sets this voltage is usually 12,500. The voltage curve of the condenser is approximately sinusoidal and the spark gap is adjusted to break down only at the highest voltage of each alternation. Hence for each cycle of the generator we get two oscillatory discharges of the condenser through the spark circuit, or 1000 wave trains sent out per second. It has been found by experiment that this frequency is most suitable for reception in the case of spark signals, due in part to more satisfactory operation of the telephone diaphragm, and in part to the ease of detection by the ear of a note of this frequency. Five hundred cycle generators are now standard equipment for radio sets on board ship.

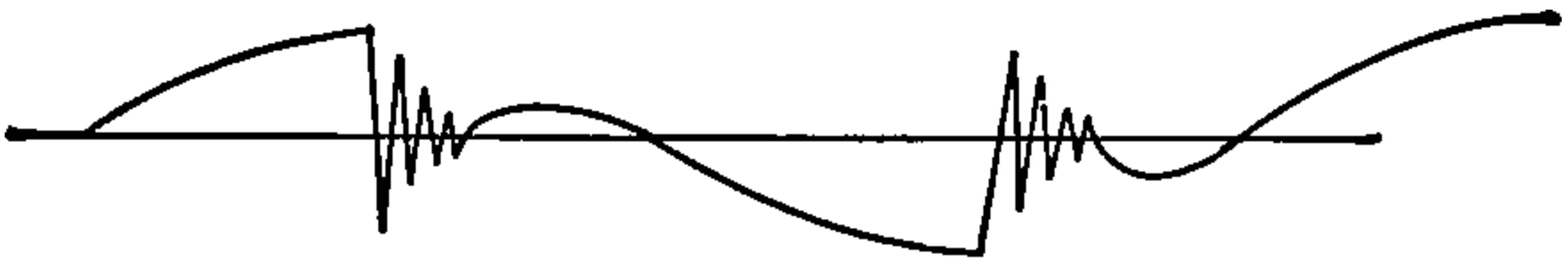

FIG. 602.

Due to the high inductance of the secondary of the power transformer, and, in high-power sets, to additional choke coils placed between the condenser and the transformer, all radio frequency current is choked off from the power circuit and the spark circuit oscillates, when the gap breaks down, as though entirely disconnected from the power circuit. The voltage of the condenser during charge and when oscillations are taking place may be represented, roughly, by curve in Fig. 602. This curve does not apply, as will be explained, when a resonance transformer is used. By "resonance transformer" we mean that the primary and secondary power circuits together with the armature windings are tuned to the generator frequency. The two circuits of any transformer may be reduced to an equivalent simple, or series, circuit. If in this case, in the reduced circuit, the capacitive reactance, at the generator frequency, is made equal to the inductive reactance, they balance each other and the impedance becomes equal to the resistance alone. It is readily seen that with the circuits thus tuned to resonance the current from the generator is in phase with the generated voltage, and is increased, due to less impedance, and the voltage on the condenser is correspondingly increased. Several advantages accrue from the use of a resonant or nearly resonant circuit, in addition to that above mentioned. In any spark circuit when the gap breaks down it becomes conductive, and for an instant practically short-circuits the secondary of the transformer, thus drawing a heavy current from the generator. With the circuits tuned to resonance any change in inductance or capacity, such as that resulting from short-circuiting the secondary, greatly increases the total impedance, thus tending to prevent this sudden rush of current. Another advantage is that the voltage obtainable on the condenser can be increased with a correspondingly lower spark frequency. Suppose the length of the gap to be increased until the breakdown voltage is slightly above that obtainable with one spark per alternation. The voltage across the condenser will rise with each successive alternation, that is, build up, as shown in the figure, until the gap breaks down. By proper adjustment we can obtain one spark for each two, three, or four alternations as desired. The voltage obtained may be several times what it would be with one spark each alternation.

It is to be noted that with resonant circuits the maximum voltage on the condenser is reached at the instant that the generated voltage and the current are both at zero value

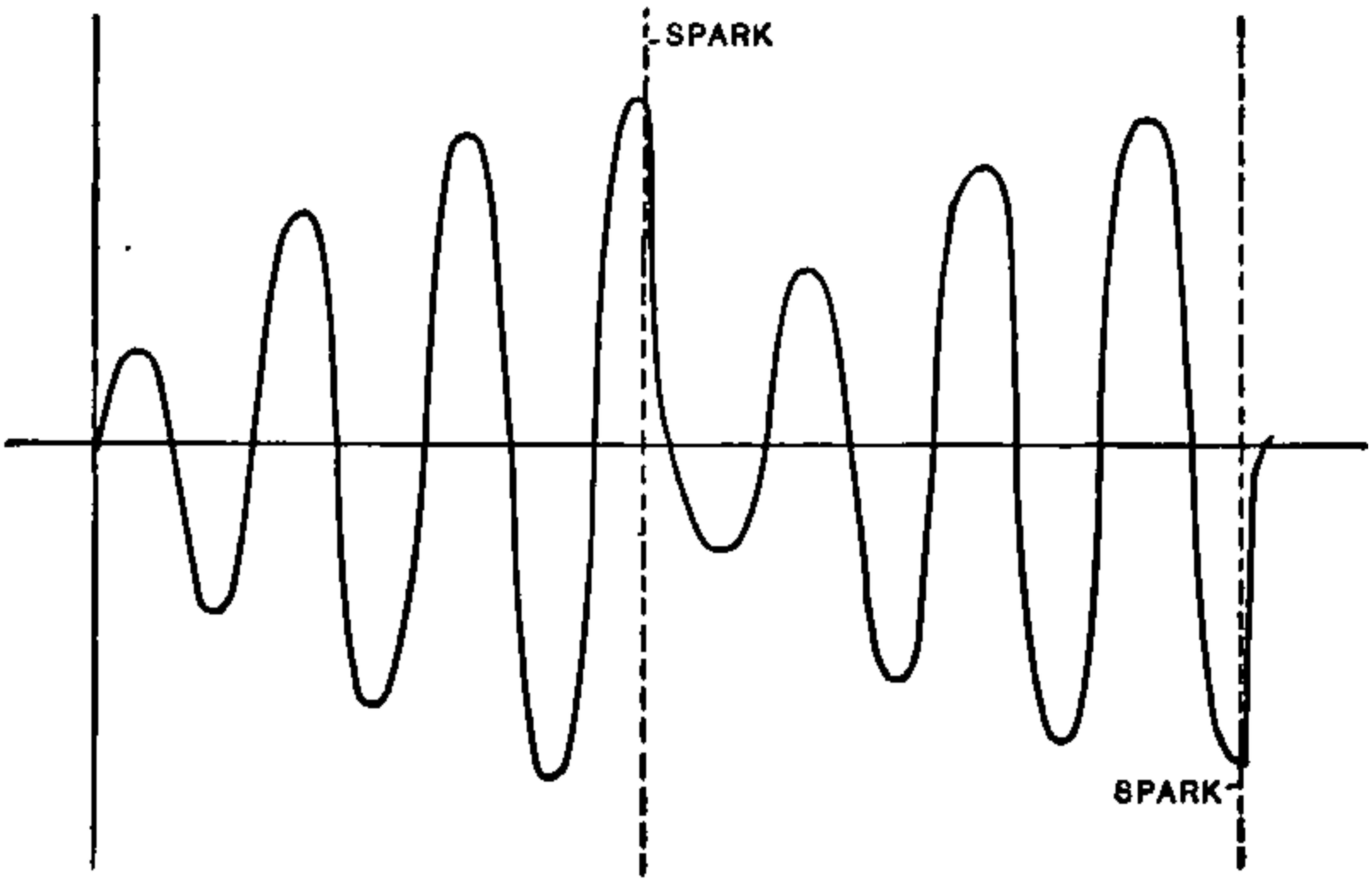

FIG. 603.—Voltage Curve with Resonance Transformer.

(see Fig. 604). The time of one complete oscillatory discharge of the condenser is small compared to the charging interval of the condenser, hence the voltage across the condenser after one or more reversals of the oscillating current

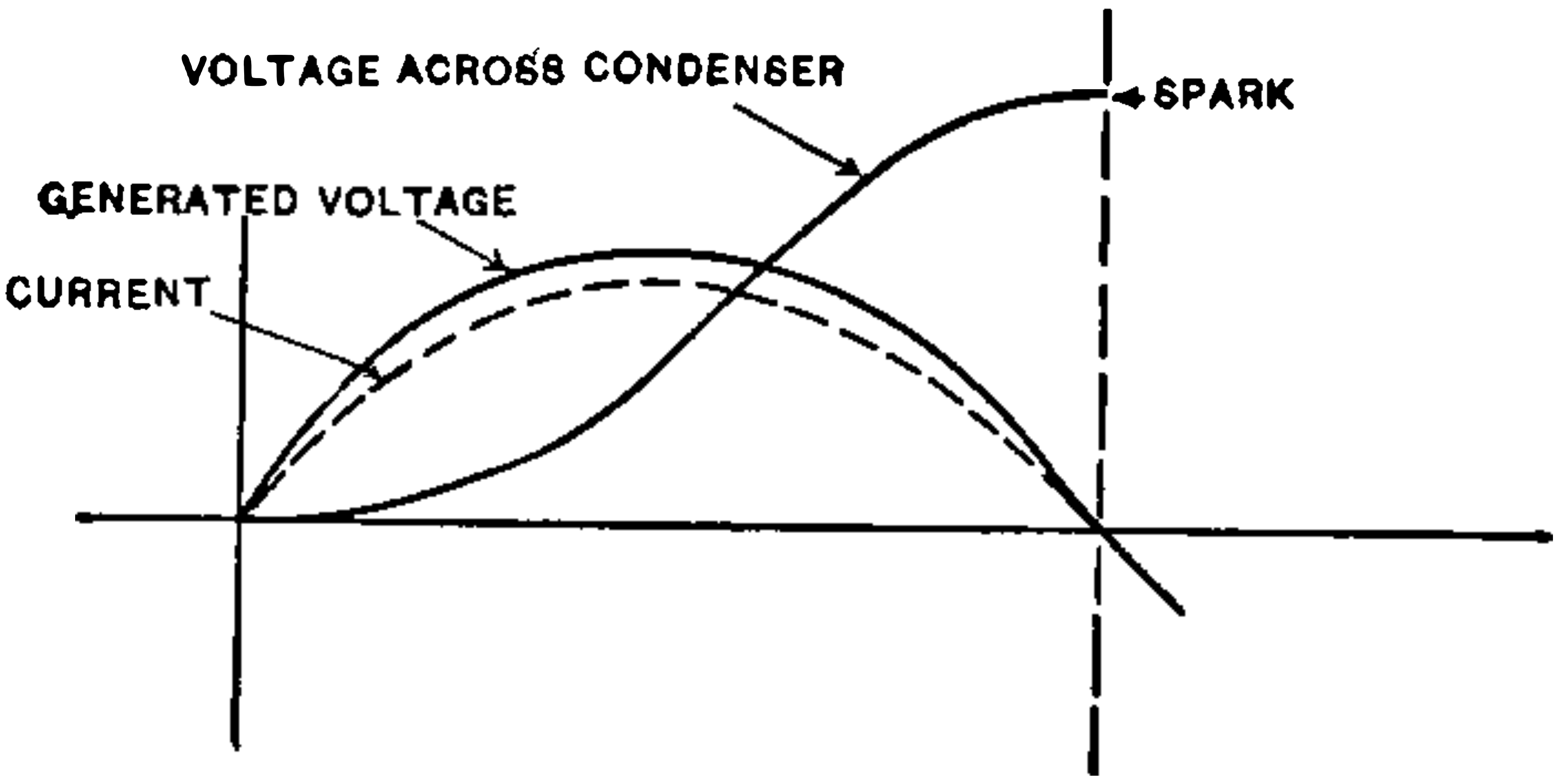

FIG. 604.

is practically that due to the oscillating current alone and is little affected by the charging current from the generator. This action may assist to a certain extent in the quenching of the spark. It can be proved mathematically that with one spark per alternation, the voltage across the condenser, when a resonance transformer is used, may be as much as 1.5 times the product of the generated voltage multiplied by the transformer ratio.

When using a quenched gap it has been found advantageous to detune the audio frequency circuits slightly from the resonant setting. This is accomplished by using a capacity in the secondary circuit about 15 per cent greater than required for resonance.

The antenna circuit is inductively connected to the spark circuit, hence has induced in it oscillations of the same, or approximately the same, frequency. Under coupled circuits, Chapter IV, we learned that under certain conditions the wave produced in the secondary of two coupled circuits might be a composite, or broad wave, that is, made up of two waves, one of slightly longer and the other of slightly shorter length than that to which the circuits are tuned. As the coupling is decreased these two waves approach each other in length until finally with extremely loose coupling a single or pure wave is produced whose length is the same as that to which the two circuits are tuned. As the coupling is decreased the energy that is transferred to the open, or radiating, circuit is decreased and also the transfer takes place less rapidly. In order to secure a pure wave and at the same time use closer coupling, with increased energy transfer, the Marconi Company devised a rotary spark gap which prevented to a large extent the re-transfer of energy from the antenna circuit back to the closed circuit. In this form of gap the spark takes place between the ends of radial spokes on a revolving wheel, and a sector mounted as shown in the figure. The distance between the sector and the ends of the spokes is adjustable so that the spark length can be varied. In the non-synchronous type the speed of the wheel is independent of the speed of the generator. In the synchronous type the wheel is mounted on an extension of the generator shaft and so placed that at or near the instant of maximum E. M. F. a spoke is opposite a sparking sector. The re-transfer of energy is prevented by the lengthening of the gap, with increase of resistance, as the spoke passes the sparking surface. This form of gap has been replaced to a large extent by the quenched gap invented by Wein (see Fig. 605). In the quenched gap we have, instead of a single long spark, a number of shorter sparks in series. The details of construction are shown in the figure. The object of the radial, fin-shaped extension to the plate is to provide a greater cooling sur-

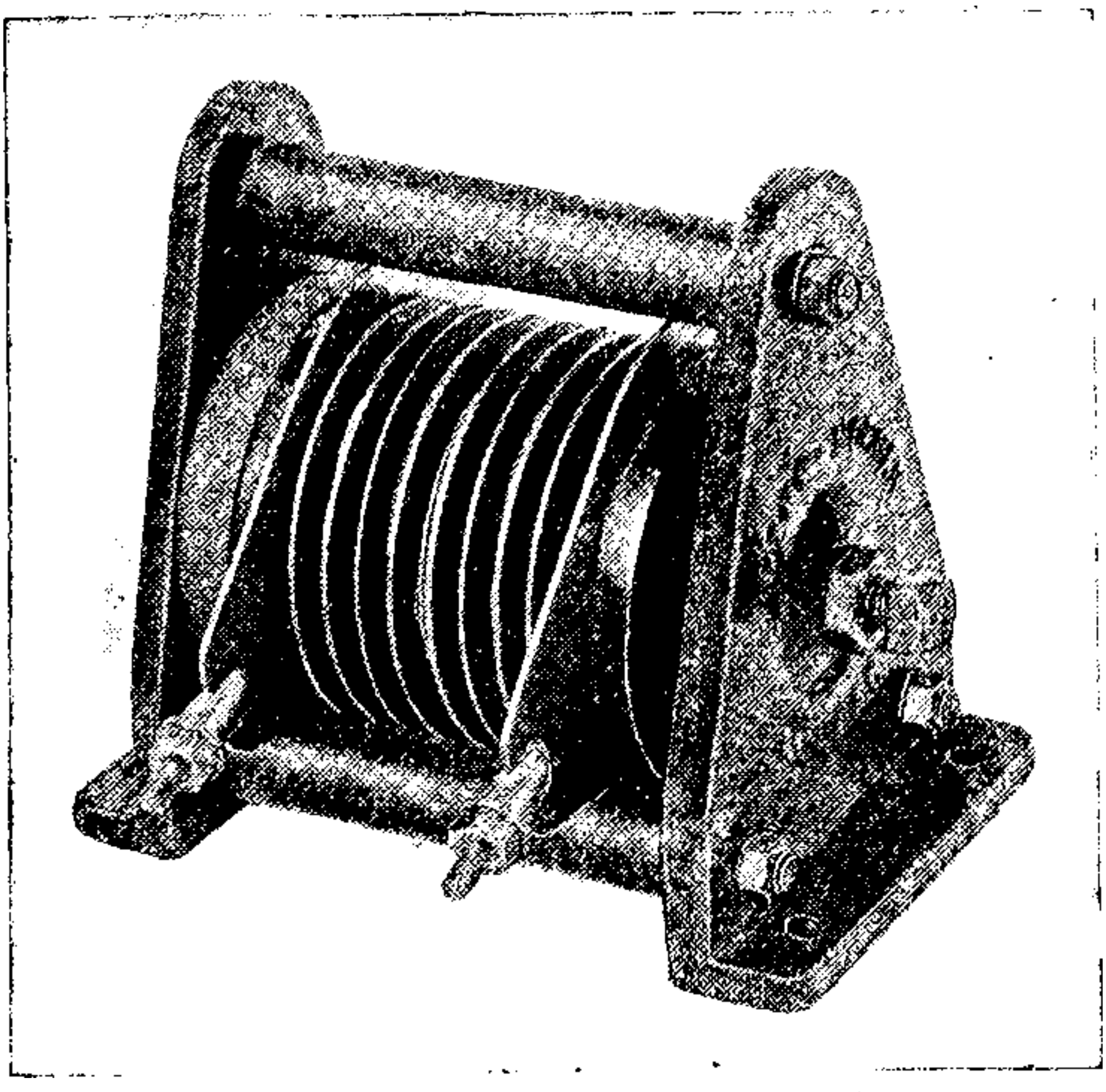

FIG. 605.—Quenched Spark Gap.

ing bolts at the ends, form air-tight chambers in which the spark takes place. The advantage of this form of gap, the prevention of a re-transfer of energy from the open to the closed circuit, is due to the more rapid de-ionization of the air or gases in the gap, thus increasing very greatly the resistance as the current dies out. As soon as the current reaches zero value the resistance is so great that the reaction from the open circuit is insufficient to again break down the gap. This leaves the open circuit free to oscillate in its own natural period. By the use of this form of gap close coupling can be used, and a larger percentage of the energy in the closed circuit is transferred to the radiating circuit, with no re-transfer and consequent loss. The percentage of energy thus transferred to the open circuit is seldom, in any set, more than 50 per cent of that delivered by the generator. These unavoidable losses take place in the transformer, condensers and leads, and as light, heat and noise in the spark gap. The energy that is transferred to the open circuit is expended, part, in overcoming the ohmic resistance of the antenna, part, in brush and corona discharges, part, as loss due to imperfect dielectric and the remainder in the form of electromagnetic radiation.

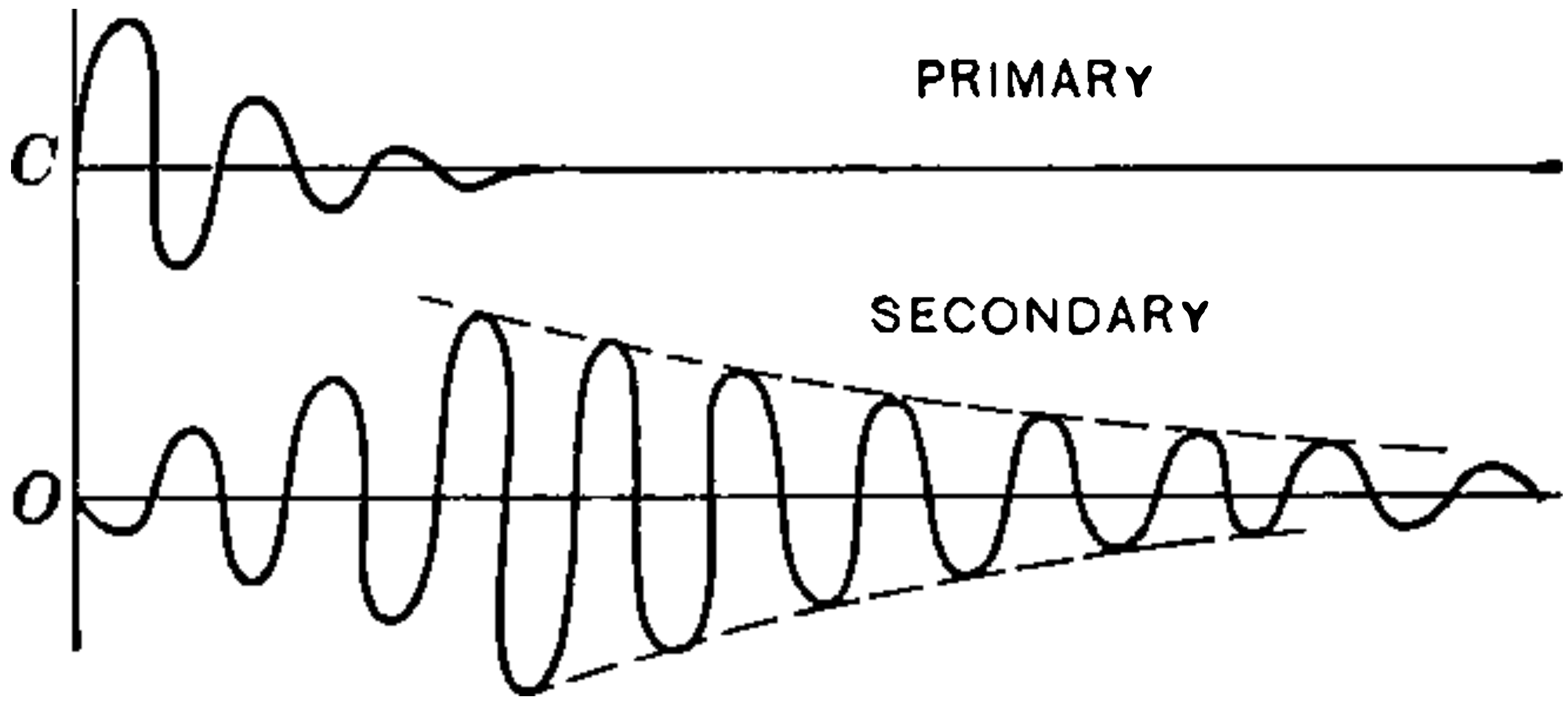

FIG. 606.—Current Curves of Closed and Radiating Circuits Using Quenched Spark Gap.

The energy radiated from a circuit, such as an antenna, is proportional to the square of the current flowing in the circuit and is thus analogous to the energy dissipation as heat in a conductor. Radiation, therefore, increases the effective or equivalent resistance by a certain amount and this increase of resistance is conveniently called "radiation resistance." It is large enough to be appreciable only in circuits of the open or radiating type or in closed circuits of large area and very high frequency. It can be computed for an antenna in terms of the effective height and the length of radiated wave.

Direct Current Spark Transmitters.

As previously noted, D. C. may be used to charge the condensers of the oscillating circuit. The connections are very simple, as shown in Fig. 607. The terminals of the condenser are connected to the D. C. generator, or storage battery, through resistance, *R,* and inductance, *L.* The inductance is usually air cored. If iron is used it is desirable to keep the magnetization well above the saturation point. The resistance in the supply line should preferably have a rapidly rising characteristic. Metal filament lamps may be used for this purpose.

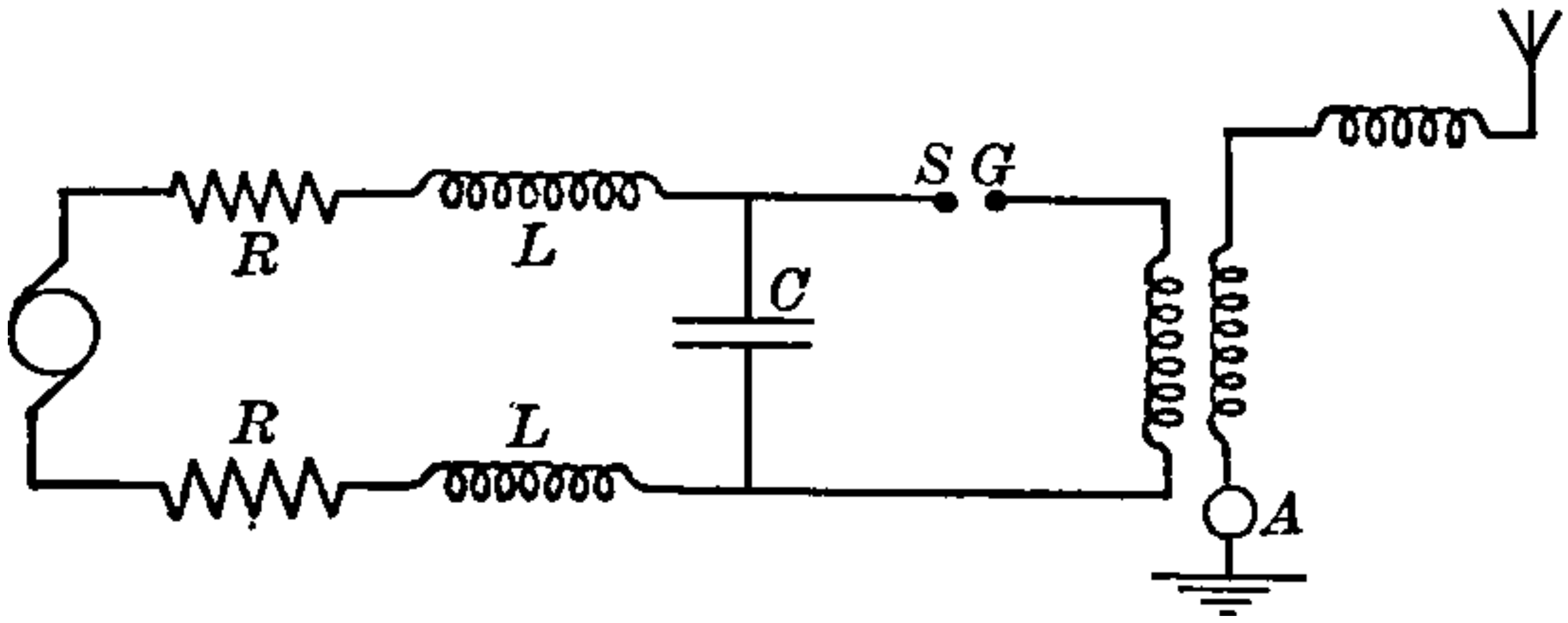

FIG. 607.—Spark Transmitter, with D. C. Supply.

If the gap length and the supply current are properly adjusted instead of an arc resulting across the spark gap we get an oscillatory discharge. The D. C. generator or storage battery charges the condenser until the potential is sufficiently high to break down the gap. The energy stored in the condenser is dissipated by heat and transfer to the radiating circuit, and potential of condenser falls practically to zero. During this oscillation the supply current is maintained practically constant by the inductance of the supply line, and due to this same inductance the high frequency currents are choked off from the D. C. line. Since the time of one oscillatory discharge is small compared to the time required to charge the condenser to the break-down potential the discharge current is almost a pure damped oscillation. Spark sets of this nature have been used by the Marconi Company in transatlantic communication between Clifden, Ireland, and Glace Bay. Some of our latest ships are equipped with a modification of this type, called "motor buzzers," which are small power sets and so designed that the oscillating circuit is completed mechanically by a revolving commutator, and

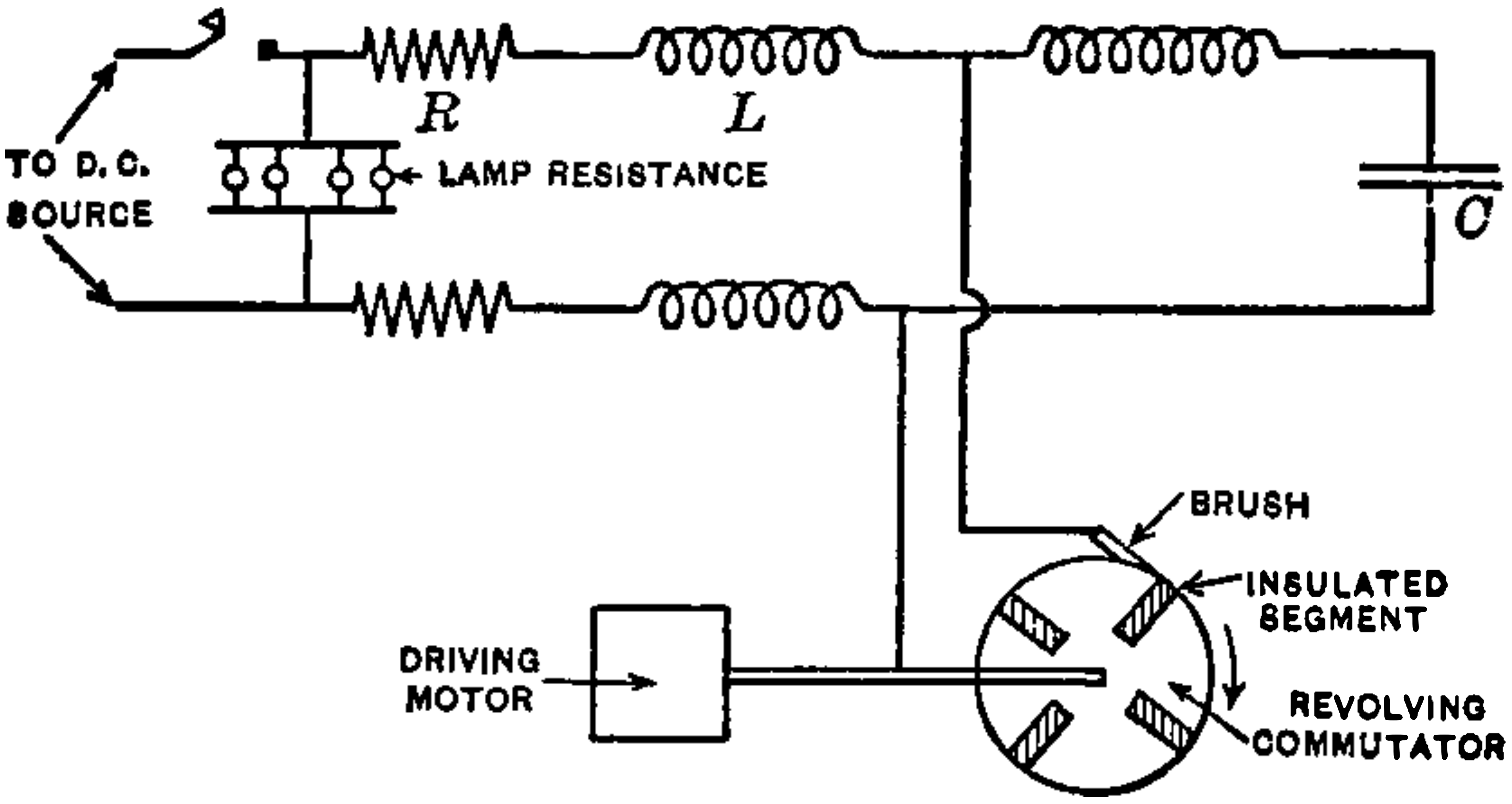

FIG. 608.—Line Diagram of a Motor Buzzer Set.

at the same instant the D. C. supply is shunted from the condenser. In this type the frequency of the discharge is regulated by the speed of the revolving commutator.

Antennæ and Fittings.

The type of antenna depends upon the location and purpose of the station. In ship installations the inverted L or T-shaped antennæ are used almost exclusively. Long-range shore stations use the umbrella type or some flat top, large capacity, type. A few of the types in use are shown in Fig. 609. The relative advantages of the various types need not be considered here.

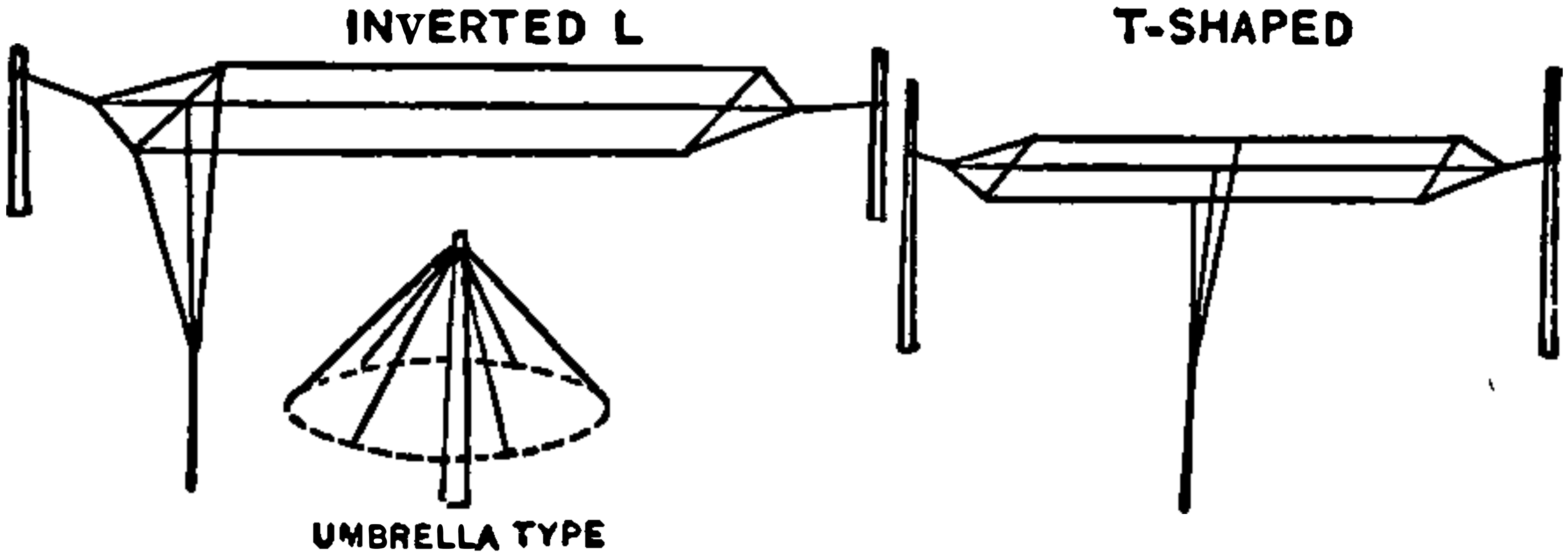

FIG. 609.

The wire used is generally stranded phosphor bronze, of low high-frequency resistance. The free or high potential end must be well insulated from the masts or towers. Bare wire is used on account of added weight that would result from insulation. The "rat tail," or lead-in, from the antenna to the sending set may be insulated wire and, where it passes through walls or decks, must be well insulated to prevent short-circuits or brush discharges.

An antenna radiates best at a frequency determined by the natural inductance and capacity of the aerial and the lead-in. Since it is impracticable to construct an antenna of sufficient size for other than short wave lengths, additional inductance coils, besides the coupling coil, must be added in series to tune the antenna to the desired wave length. The wave length to which the antenna is tuned. by adding inductance, should not, for efficient operation, exceed four or five times the fundamental or natural wave length.

The radiating circuit consists of the aerial, lead-in, ground connection, ground, and capacitive connection between ground and aerial, thus forming a series circuit. It is readily seen that a good ground connection is essential in order to keep the resistance of the circuit low. Dry earth is a poor conductor, hence the ground connection must be extended far enough below the surface to insure intimate contact with moist earth. In the case of ship sets the hull furnishes an excellent current path to the conductive sea water. On shore the ground connection is often in the form of numerous wires placed well below the surface of the earth and radiating in all directions from the transmitter. Instead of a direct connection to earth, we may use a "counterpoise," *i. e.*, a network of wires connected to the lower end of the antenna and parallel to, but insulated from the earth. The aerial and the counterpoise respectively form the two plates of a condenser, with the electrostatic field between. This is the nature of the antenna circuit in an airplane transmitter. The counterpoise may be attached to the upper surface of the wings and the antenna trailed below. The use of a counterpoise in connection with a flat top antenna tends to give a more uniform distribution of the electric strain lines.

Notes on Installation and Tuning of Spark Transmitters.

The efficiency of a transmitter is materially affected by the manner in which the circuits are laid out. A changing magnetic flux induces a current in any circuit or piece of metal lying wholly or in part in the field of the flux. Such induced currents in other than the regular circuits of the set represent lost energy. Radio frequency circuits of a transmitter should be so placed with reference to bulkheads, receiver circuits, etc., as to reduce to a minimum these stray currents. Crossing leads are to be avoided. The receiver should be placed as far as practicable from the sending apparatus, and all circuits should be mounted on insulating material. Much loss of energy can be avoided by keeping all parts of the set perfectly clean.

For safety all high voltage circuits, transformer terminals, etc., should be protected from accidental contact.

Assuming the set to be installed, the following procedure is required to put it in shape for transmission. If a rotary gap is being used, the power circuits may be adjusted to resonance to the generator frequency. With a quenched gap the natural frequency of the power circuits should be slightly lower than the operating frequency. Resonance curves can easily be plotted, and should be plotted for all sets when installed. An easy method of plotting a resonance curve for the power circuits is as follows: Insert an ammeter in the generator armature circuit, and, keeping the frequency constant, plot amperes in primary circuit against capacitance in the secondary circuit. The point of maximum current in the primary circuit determines the resonant setting. A variable reactance is usually inserted in the primary circuit. This reactance regulator, as it is called, may be variable by steps or continuously, by means of a sliding iron core. These adjustments are usually made by the manufacturer. In some cases a double throw switch is provided, connecting to two taps on the reactance regulator, one contact giving a condition of resonance for full power, the other giving increased impedance for low power.

Having made or checked the adjustments of the power circuits, the next step is to tune the oscillating or spark circuit to the desired wave lengths. To do this disconnect the antenna circuit entirely, close sending key. Examine the circuit carefully to see that there is no "sparking over," that contacts are good and that gap is operating properly. Bring a wave meter near the circuit and measure the wave length of the oscillation produced. Release key, vary the inductance and measure wave length again. A few trials will suffice to adjust to desired wave length. The inductance may thus be calibrated for several wave lengths and marked so that to change the wave length it is only necessary to tap off at the proper point. Next connect up the antenna circuit, with all or a part of the coupling coils in series. Press key and observe the reading of the hot-wire ammeter in antenna circuit. Vary the inductance of the antenna circuit until the reading of the ammeter is a maximum. The two circuits are now tuned to the same wave length. Vary the degree of coupling between the two circuits and observe the effect on current in the antenna. It will be found that there is one best degree of coupling; any change, either increase or decrease, will decrease the current in the antenna. This degree of coupling can be obtained by varying the distance between the coupling coils or by varying the number of turns of coupling coil in use. In the latter method any change in turns of coupling coils necessitates an inverse change in the loading coil to keep

CHAPTER VII.

CONTINUOUS WAVE TRANSMITTERS.

The following devices for producing approximately pure undamped oscillations will be explained. First, the radio frequency alternator; second, the radio frequency spark; third, the arc; fourth, the vacuum tube.

For mechanical reasons the inductor type of alternator is used for high frequencies. There are two principal mechanical advantages of this type. One is that the revolving parts do not carry windings. The other is that for a given number of poles on the revolving part the frequency produced at any speed is just twice that which would be produced by the ordinary construction. It should be known that the inductor type of alternator is by definition "an alternator in which both field and armature windings are stationary, and in which masses of iron or inductors, by moving past the coils, alter the magnetic flux through them." This type of alternator or A. C. generator has the magnetic flux through all parts of the magnetic circuit *constantly in the same direction.* The part of the flux which passes through the armature winding is varied by changing the reluctance of the magnetic circuit through this winding. This change of reluctance is, in turn, due to changing the length of an air gap in this magnetic circuit. The change in the length of air gap being produced by passing the soft iron through the air gap. It will be seen that as one inductor approaches an armature coil, the flux through the coil will rise from its minimum value to a maximum, and as the inductor recedes from the coil the flux through it will decrease to its minimum value again. The increasing flux through the coil produces a voltage in the coil in one direction, the decreasing flux produces a voltage in the opposite direction. The result is that the passage of *one* inductor in front of a coil produces a complete cycle of A. C. E. M. F. in that coil. In the Alexanderson alternator, which is a representative type of radio frequency alternator, the inductors are spokes on the edge of a steel disc. The steel disc and spokes in this case have a mechanical construction very nearly the same as that of the DeLaval turbine, the disc being thickened near the shaft with the object of producing a uniform distribution of the stresses and consequent maximum strength of the whole. The peripheral speed is extremely high, that is, in the neighborhood of 12 miles per minute. This very high speed in connection with a relatively large number of poles permits the direct production of radio frequencies corresponding to the longer wave lengths. The very great rate of change of position of the parts of this alternator permits the production of a reasonable voltage with only one turn of wire per armature coil and not a very large change of flux through the coil. This alternator may be connected either directly in series with the antenna, or it may be coupled to it by means of a transformer. In either case the antenna system will be tuned to the wave length produced by the generator. Transmission of signals may be accomplished in a number of ways. A very simple way short-circuits some of the turns of the antenna loading coil. This throws the antenna out of resonance with the applied E. M. F. and thereby greatly decreases the current in the antenna. Changing the field excitation of the alternator is another possibility. See Chapter X for other methods of controlling the output of a radio frequency alternator.

The production of undamped waves by means of sparks occurring at radio frequencies may be divided into three classes according to the method of controlling the time between sparks. In the first class are those types of apparatus in which there is no accurate timing of the sparks. In the second class are those types of apparatus in which the timing of the sparks is produced mechanically. In the third class are those types of apparatus in which the timing of the sparks is produced electrically.

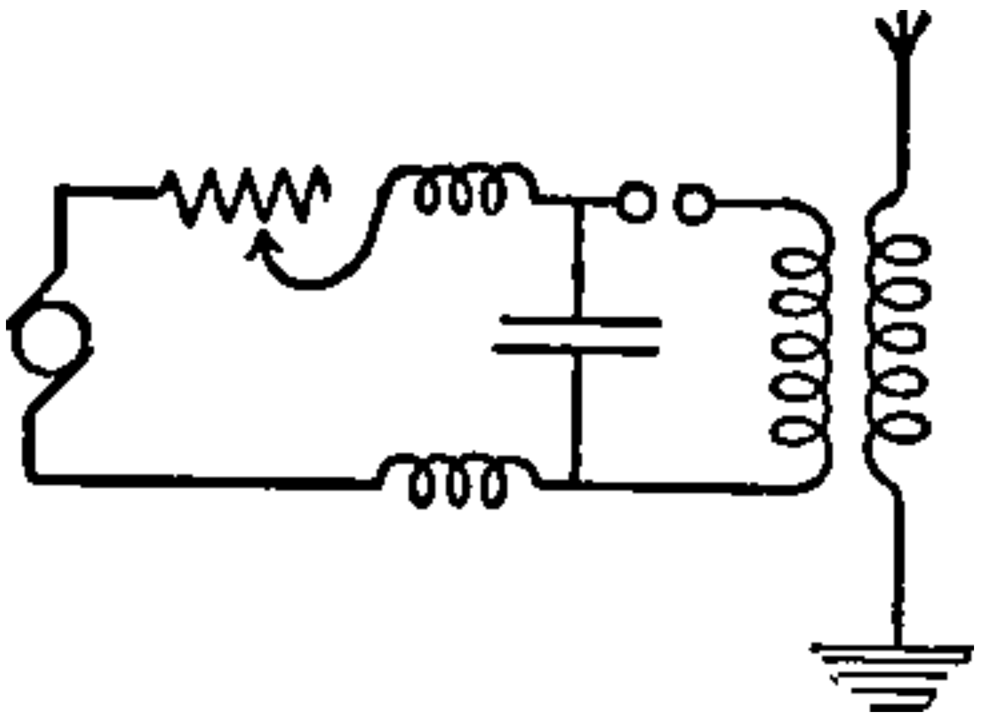

FIG. 701.

Consider the circuit of Fig. 701. This is a type of circuit which is used for the production of ordinary damped oscillations, using D. C. supply of power. The time between sparks with this circuit depends upon the time taken to charge the condenser to a voltage at which the spark jumps the gap. As the voltage required to jump the gap varies with the degree of ionization of the gas in the gap, the time between sparks will not be perfectly uniform. As the supply current to this circuit is increased the time between sparks becomes shorter, and with suitable gaps the current may be increased until the sparks occur at such short intervals that the current in the antenna never has a chance to die down to zero value. This produces an approximation to an undamped oscillation. Due to the slight irregularity in the time of occurrence of the sparks and the fact that there is no special relation between the number of sparks and the frequency of the undamped wave, the current in the oscillating circuit not only varies be-

times by rotary gaps all mounted on the same drive shaft. This difference of time is illustrated in the figure by the fact that the two rotary gaps are displaced 45 degrees from each other. The antenna current is, of course, a summation of the currents which would be produced in the antenna by the separate primary circuits. As the new damped waves in the primaries are timed so as to always assist the oscillation already existing in the antenna, this should be the sum * of the separate damped waves which the primaries tend to produce in the antenna. It is possible to arrange by this system that a new damped wave shall be started in some one of the primary circuits at the beginning of each cycle of current in the antenna system, at the beginning of every other cycle, or at any other regular sequence. The final resultant current in the antenna is a very close approximation to a pure undamped wave, if the sparks are not spaced too far apart. Heterodyne or autodyne reception of the wave produced by this system gives a good note. Transmission of signals would seem to be most logically performed either by detuning the antenna or by interrupting the D. C. supply.

A number of electrical means of controlling the time of the spark are available. The action of the Chaffee gap will be explained to illustrate one of these.

A Chaffee gap for use on D. C. consists of two plane parallel metal faces of a few square centimeters area, one of aluminum and one of copper, separated by a few mils and operated in an atmosphere of moist hydrogen.† Al-

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* *Not* the simple arithmetical sum, but rather a square root of the sum of the squares of the separate currents, so that the energy represented *would be* the arithmetical sum of the energies from the separate sources.

† Alcohol vapor is also suitable.

though not called a quenched spark gap, the Chaffee gap may be thought of as being the most extreme thing in the way of a quenching gap. Due to the materials of the gap and the conditions of operation, a single spark discharge across the gap produces only one alternation or impulse of current; that is, this gap puts the spark out the first time that the instantaneous value of current reaches zero. The excitation produced by the action of a current such as this is known as impulse excitation. It corresponds roughly to putting a bell into vibration by hitting it with a hammer. One result of this impulse excitation is that the energy is transferred from the primary to the secondary in the time of one cycle or less of the current in the secondary. Another effect of this almost instantaneous quenching of the spark is that no matter how closely the secondary is coupled to the primary only the one wave length to which the secondary is tuned appears in the secondary. Furthermore, as the primary does not continue to oscillate so that it might get out of step with the current which it starts in the secondary, the primary circuit does not need to be tuned to the secondary.*

The circuit shown in Fig. 701 is suitable for the operation of a Chaffee gap, the actual circuit differing from the one discussed before only in the use of the Chaffee gap and *very close coupling* between the primary and secondary circuits. When D. C. is supplied to the condenser it charges until a voltage in the neighborhood of 500 is reached, the gap then breaks down and the discharge of the condenser produces the pulse of current in the primary. The gap

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* The wave length adjustment of the primary for maximum results in the secondary is very broad, but maximum results have been obtained with the primary tuned to a wave length about 70 per cent greater than the secondary wave length.

then becomes non-conducting and the condenser starts to recharge. The voltage now acting to tend to break down the gap consists of two parts, that due directly to the quantity of electricity which has gone to charge the condenser, and that induced in the primary by the action of the oscillating current in the secondary. Naturally the gap will break down at some point of the antenna current cycle when these two voltages are acting in the same direction. If the current supplied is large enough to charge the condenser in the time necessary for, say, not over six cycles of the antenna current, with any given supply current the gap will break down at the time the secondary current reaches a certain definite point in its cycle. This gives a *regular* cycle of events in the antenna circuit, instead of the erratic action due to a circuit such as the first one explained above under sparks at radio frequency. This definite point on the cycle at which the gap breaks down may not be reached until after from one to six (or possibly more) cycles have passed without a breakdown of the gap occurring. The number of cycles occurring between discharges across the gap is controlled by the rate at which the condenser is charged. The point on the secondary current cycle at which the gap breaks down is determined principally by the voltage induced in the primary by the secondary. It may be seen from the preceding that the approximate control of the time between sparks is due to the variable resistance in the supply circuit, while the accurate control of the time of the spark relative to the secondary current is controlled automatically by the induced E. M. F. Apparently, if a new impulse is given to the antenna system every other cycle, or every third cycle, the current flowing in the antenna system cannot depart appreciably from a pure undamped wave.

been in operation so that the conditions are those corresponding to steady operation. If by any means the arc is extinguished, the current supply all goes to the relatively small capacitance C, the voltage across the gap rises very rapidly and the point is soon reached where the voltage is high enough to jump the gap between the electrodes. The supply current now transfers itself from the condenser circuit to the circuit through the arc, and the condenser starts to discharge through the arc at a rate determined principally by the small inductance L_2 (a few millihenries). The condenser current adds to the supply current flowing through the arc thus producing an instantaneous value of current through the arc considerably greater than the supply current. Due to the inertia effect of L_2, the current through the circuit CL_2 does not stop when the condenser is discharged. It continues until the condenser is recharged in the reverse direction almost as highly as the original charge, and then starts to discharge in the opposite direction. It must be noticed that at this point in the cycle the current through the arc is the *difference* between the supply current and the current in the oscillating circuit formed by C and L_2. For this reason as the current in the oscillating circuit rises toward its maximum value, the current across the arc decreases. When the arc current approaches zero the resistance of the arc becomes so high that the arc goes out entirely. This completes one cycle of the generation of the undamped wave.* For ordinary

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* The action given in this elementary explanation is supplemented by the change of resistance of the arc with change of current during the time when the current is flowing. The resistance of the arc being much higher for small currents than it is for large currents.

operation the time during which the arc is out is only a small portion of the total time for the cycle. The approximate nature of the current through the arc, and through the oscillating circuit is shown in Figs. 704A and 704B respectively.

The point *A* in Figs. 704A and 704B is the point at which the voltage becomes high enough to jump between the electrodes. During the time from *A* to *B* the supply current is being transferred from L_2 to the arc. From *B* to *C* the condenser is discharging through the arc *with* the supply current. At *C* the current through the oscillating circuit reverses, and from *C* to *D* the effect is that of the supply current and oscillating circuit current trying to pass through the arc in opposite directions. During this period the supply current is transferred from the arc to L_2. At *D* the arc current reaches zero and tends to reverse, but is prevented from reversing by the arc going out. From *D* to *E* there is no current in the arc, the entire supply current going directly through L_2 to charge condenser *C*. At *E* the voltage between the electrodes becomes high enough to jump the gap, and the preceding cycle starts again. The dotted line in Fig. 704B shows the current which would flow if the first oscil-

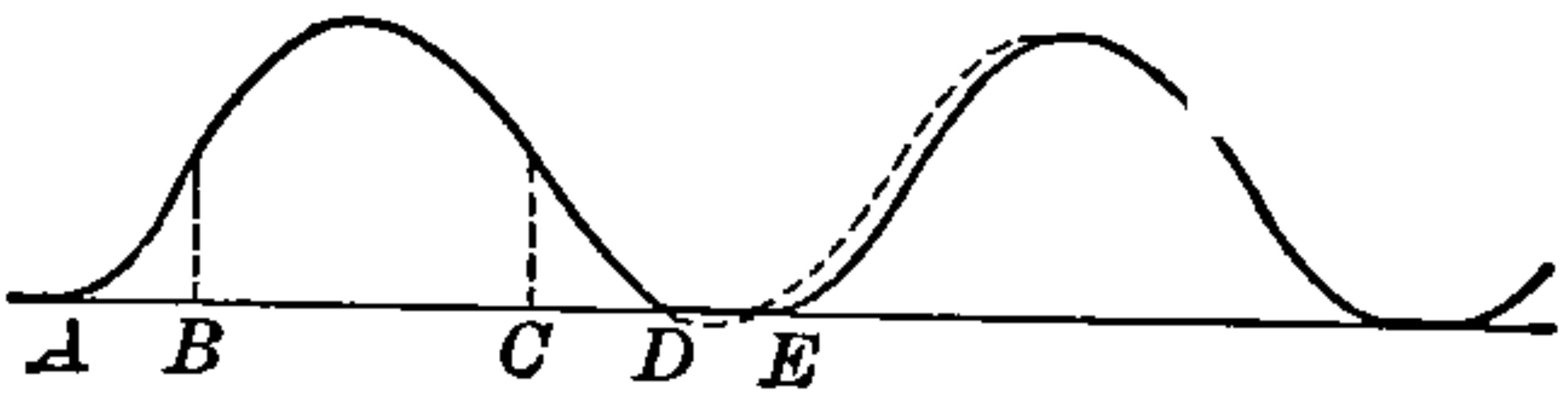

FIG. 704A.

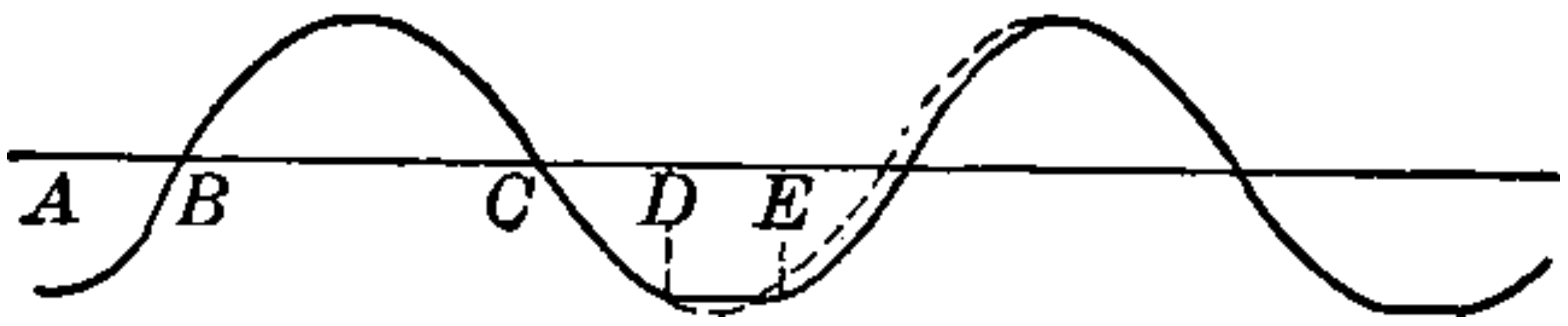

FIG. 704B.

lation continued without interruption. Evidently the frequency of this approximately undamped wave will be at least slightly lower than the frequency determined by the *L* and *C* of the oscillating circuit. As this difference is due to the time during which the arc is out, and this time may vary with length of arc, etc., the frequency generated by such a system may not be perfectly constant.

To enable the arc to follow at radio frequencies the cycle of operation outlined above, several special provisions are necessary. The electrodes used for the arc consist of an ordinary solid carbon for the negative, and a water-cooled copper piece for the positive. The arc is surrounded by an atmosphere consisting largely of cool hydrogen,* and is operated in a magnetic field. The cool copper electrode and hydrogen atmosphere both make the resistance of the arc very high for low currents (and susceptible to rapid changes) and consequently tend to put the arc out altogether whenever the current reaches a low value. The magnetic field is placed so as to deflect the arc from the straight line between the electrodes thus increasing the length and resistance of the arc, and at the same time tending to blow it out altogether. Hydrogen is also more susceptible to very rapid *changes* of ionization (upon which the conductivity of the arc depends) than any other gas. The combination of these features permits the construction of

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* The chamber in which the arc is enclosed is water jacketed, thus cooling the gas in which the arc operates, and to a certain extent cooling the carbon electrode. The gas is usually obtained by vaporizing alcohol or kerosene. Kerosene when decomposed by heat gives principally hydrogen and soot. Alcohol when decomposed by heat gives hydrogen, some carbon dioxide, and small quantities of soot.

coil links with it, will have currents produced in it which tend to prevent the setting up of the magnetic field. This will reduce the total flux cutting the loading coil and will, therefore, reduce its effective inductance. A loop such as this may be made of such size that the current and voltage in it are not excessive for one pair of contacts to handle. More separate loops, each having its own contacts, can then be added until the desired decrease in the effective value of the inductance of the loading coil is produced. This produces the same effects on the antenna as short-circuiting the turns of the loading coil, but has the advantage of dividing the current and voltage to be handled among a large number of contacts. A large number of contacts has also another advantage. If out of, say, 50 independent sets of contacts two or three fail to operate, the change in the results on the transmission does not amount to much, and these contacts not being connected to the main circuit may be repaired without stopping transmission. In any case, the contacts would be operated by means of solenoids which would be either directly or indirectly controlled by a telegraph key. Fig. 706 shows a circuit used for extinguishing and reigniting the arc. The direction of the magnetic field in this figure is such as to drive the arc toward the lower right-hand corner of the figure. The resistance R is of such value that when connected in series with the large inductance the combination will draw a current equal to the normal cur-

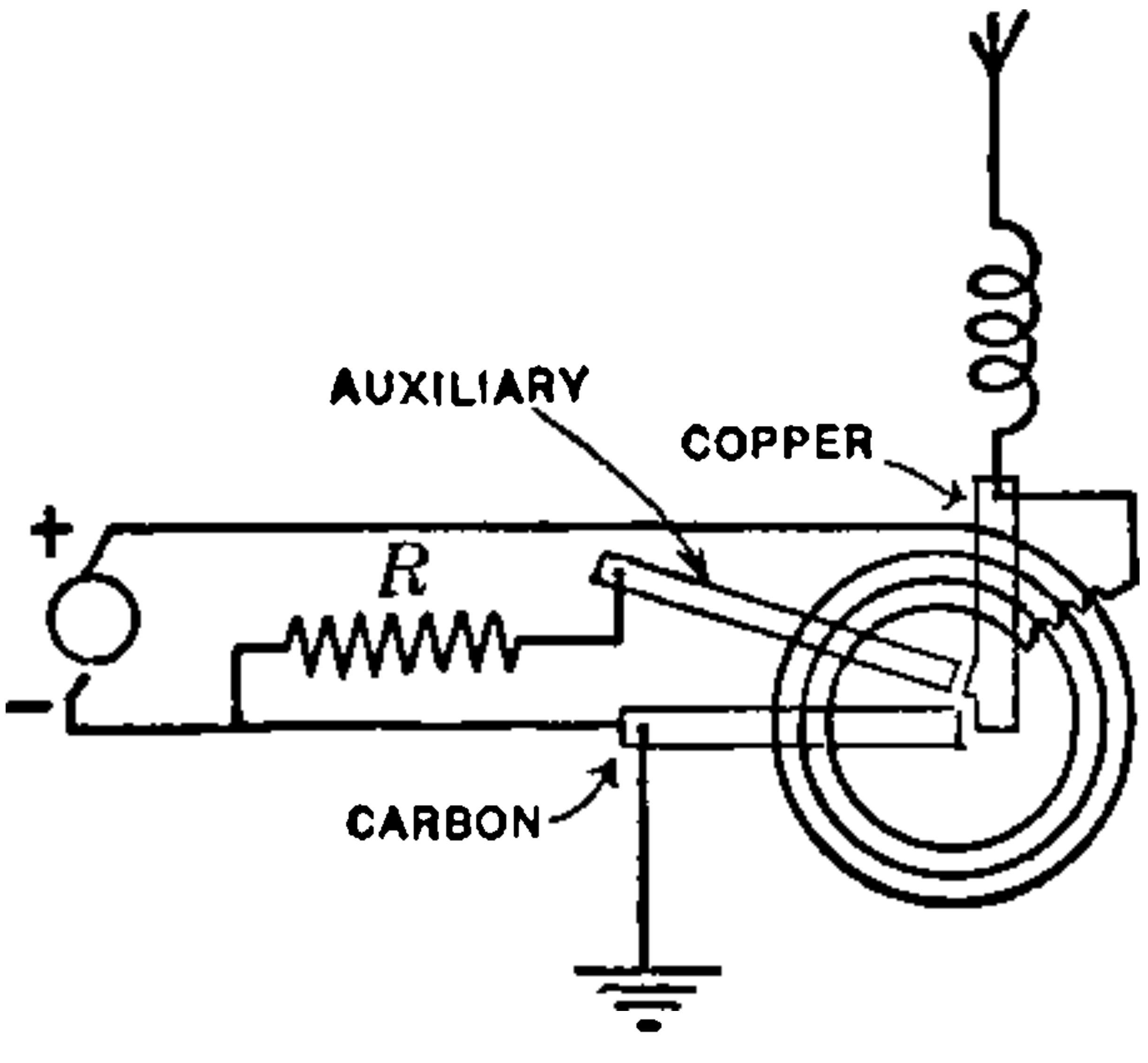

FIG. 706.

rent for the arc. When it is desired to stop the arc the copper contact marked "Auxiliary" is slid in until it strikes the positive electrode, thus putting the resistance *R* in parallel with the arc. To start the arc again within a short time, all that is necessary is to pull out the auxiliary contact. The instant that the auxiliary contact leaves the main electrode an arc is formed between the two. The magnetic field blows this arc toward the lower right of the figure and against the carbon. If the auxiliary gap is not too short, the arc is again established between carbon and copper, and normal operation of the arc is resumed, with no current in the auxiliary circuit. The motion of this auxiliary electrode is controlled by means of a solenoid which is controlled by a telegraph key. This system is probably desirable only on low power arcs.

To start a Poulsen arc it is necessary to put a resistance in series with the arc and choke coil to prevent excessive current when the arc is struck. The negative electrode is then moved into direct contact with the positive electrode. In this condition the flow of current is limited by the added resistance and the resistance of the choke coil (which latter is usually large enough so that no other resistance is needed during normal operation). When the electrodes are drawn apart an arc will be established if a suitable separation of the electrodes is used. The extra resistance can then be short-circuited leaving the arc in normal operation. The best length of arc is judged by the current produced in the antenna system. After a steady operating condition has been established, the arc can be extinguished and reignited by means of the auxiliary electrode, if this is provided.

As the generation of undamped oscillations by means of vacuum tube circuits has been discussed in some detail, the discussion at this point will be limited to the application of the generating circuits to antenna systems.

The applications of vacuum tube generating circuits to antenna systems may for convenience be divided into three classes. In the first class are those types of circuit in which the antenna is connected in place of one of the condensers in an oscillating circuit of the generating system. This may be thought of as direct connection. In the second class are those types of circuit in which the antenna is coupled to an oscillating circuit of the generating system. This is usually connection by transformer action. In the third class are those types of circuit in which the output of the generating circuit is passed through one or more steps of radio frequency amplification before being applied to the antenna.

In considering these various types it should be kept in mind that the resistance of any particular antenna at a given wave length has a fixed value which cannot be changed without changing the antenna circuit. If a generating circuit is capable of supplying a certain power P to an antenna, the current to be produced in the antenna, or the voltage to be applied to the antenna, must be capable of determination from the expressions $P=I^2R=E^2/R$, where I is the current in the antenna, E is the voltage applied to the antenna, and R is the total effective resistance of the antenna (including radiation resistance). From these expressions it is seen that under the given conditions, I and E have but *one* value, $I=\sqrt{P/R}$ and $E=\sqrt{PR}$. If it is

circuit to an antenna. The tube at the right, in this case, would be one of much larger power capacity than the generating tube.

Circuits of the first type described above have the advantage of simplicity, and having a minimum amount of conductors in which current is to be set up, tend to have a minimum amount of losses and consequently maximum efficiency. If anything happens to the antenna to change its constants, the power output of the system will not be greatly affected, but the wave length will be.

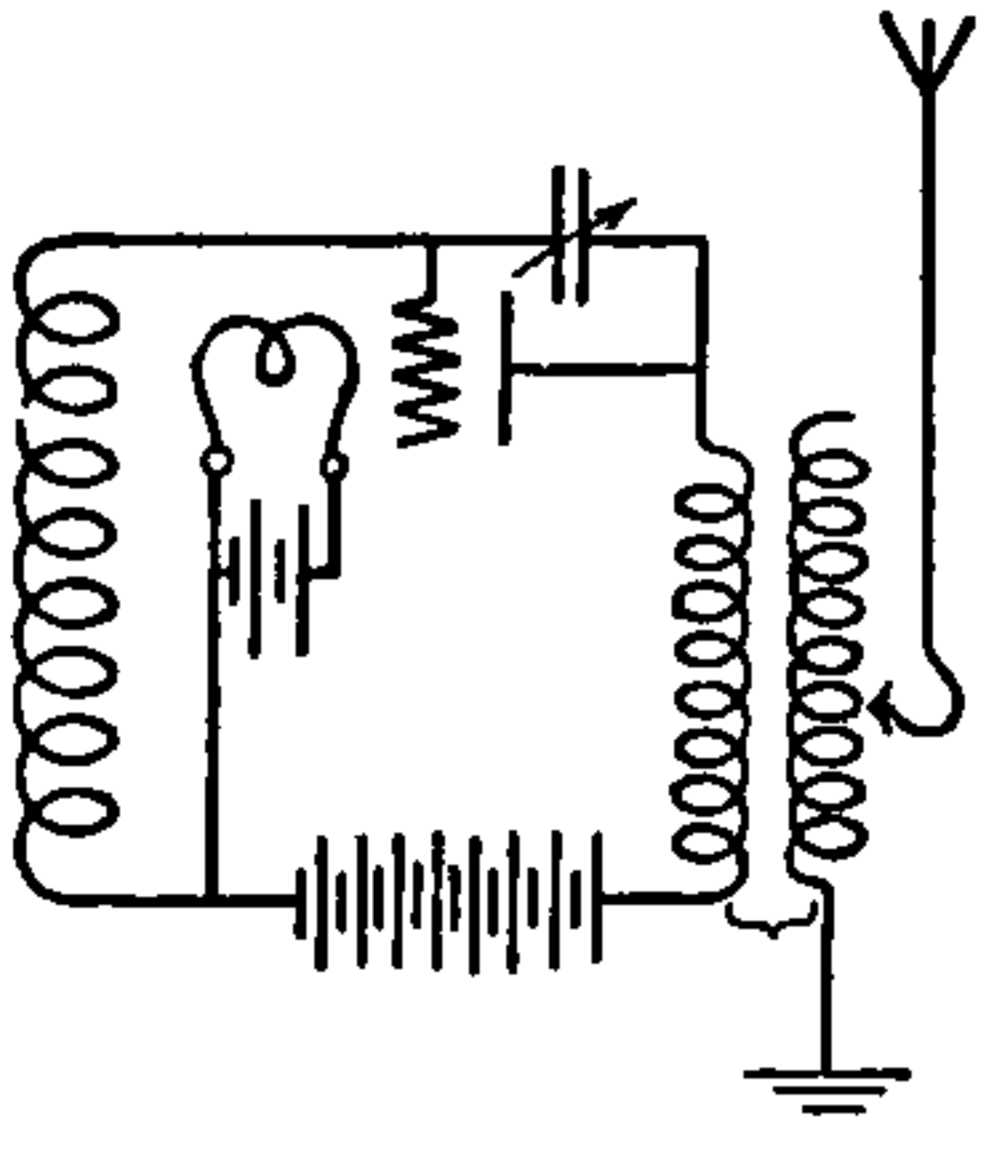

FIG. 708.

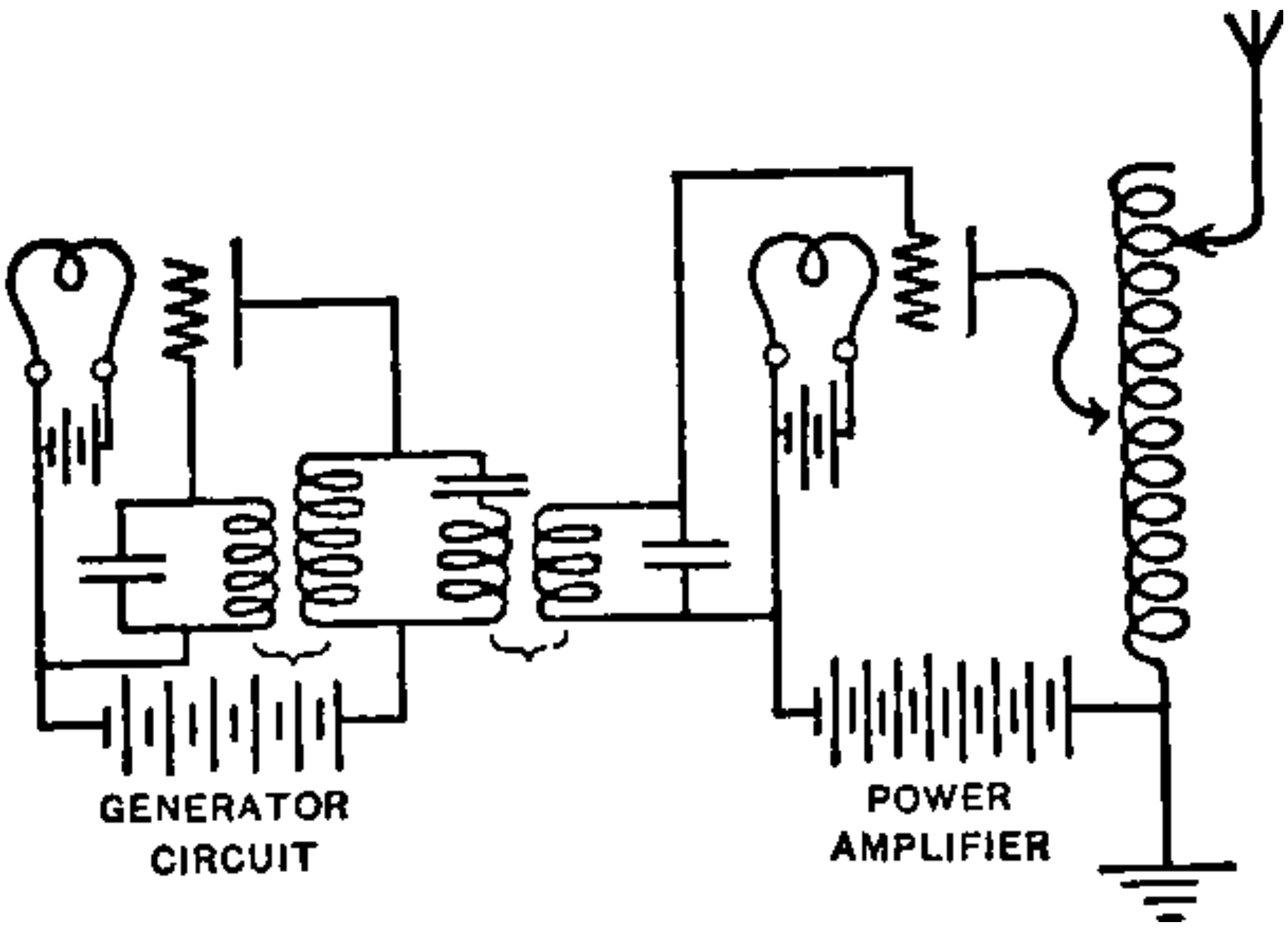

FIG. 709.

The second type is almost equivalent to the first, but is slightly more complicated, and tends to be correspondingly less efficient.

The third type of circuit has as its principal peculiarity that the tuning of the *antenna* has no appreciable effect upon the wave length transmitted. If the antenna is not tuned for the wave length to be transmitted, the power output is decreased, but this does not affect the wave length. This may be of importance, particularly under military conditions, where many slightly different wave lengths are being used simultaneously. Poor work in setting up the antenna and tuning it, or an accident to the antenna after setting it up will not prevent communication with a receiving station waiting to receive on the wave length to which the *generating circuit* is tuned (unless, of course, the distance approaches the maximum that the set can transmit). In wireless telephone apparatus this set may have another type of advantage. A wireless telephone circuit usually uses one bulb in a generating circuit and another bulb of the same size to control the output of the generating circuit. If large output is desired a small generating bulb and small control bulb may be used and then a radio frequency amplifier with one large tube (instead of using two large tubes, one for the generator and the other to control the output of the generator).

A grid condenser and grid leak, such as shown in Fig. 707, are usually used with a vacuum tube generating circuit to enable the grid to be kept at a desirable negative potential. For whenever the grid becomes positive, current flows in the tube from the grid to filament causing a loss of power. The insertion of the grid condenser and a grid leak of suitable value automatically keeps the grid sufficiently negative that only the top tips of the positive alternations of A. C. applied to the grid make the grid positive. When the circuit starts to generate the grid is at the potential of the terminal of the filament to which the grid leak is connected. The A. C. applied to the grid at first makes the grid highly positive for each positive alternation. This causes current to flow away from the grid through the tube, thus making the *average* voltage of the grid negative. The *average* grid voltage will continue to become more negative until a balance is reached between the current flowing away from the grid through the tube and the current flowing to the grid through the grid leak. Frequently, if the grid leak is disconnected, the grid will become so highly negative that the oscillations will stop altogether. The negative charge may then leak away slowly, with the result that the tube starts to generate again, builds up a high negative charge on the grid and then stops again, thus producing intermittent oscillations.*

To use any of these vacuum tube generating circuits for undamped wave telegraphy, the transmitted wave length may be changed by making a change in the oscillating circuit of the generating tube. It is usually more convenient to stop the oscillations altogether, by interrupting the D. C. supply, by opening the grid circuit, or sometimes by opening the grid leak circuit. For the use of these circuits with radio telephones see Chapter X.

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* For a more detailed description of the effects of the average value of grid voltage, see Figs. 1015 and 1016, and accompanying explanation.

(This “leak” reduces the efficiency of the detector and is tolerated only because a better cycle of action has not been produced.)

A theoretical curve showing the variation of current through a detector of the above type, for the simplest case, is shown in Fig. 801. It is seen here that a voltage applied in one direction will produce a much greater flow of current than an equal voltage applied in the opposite direction. A practical curve of a similar type is shown in Fig. 802.

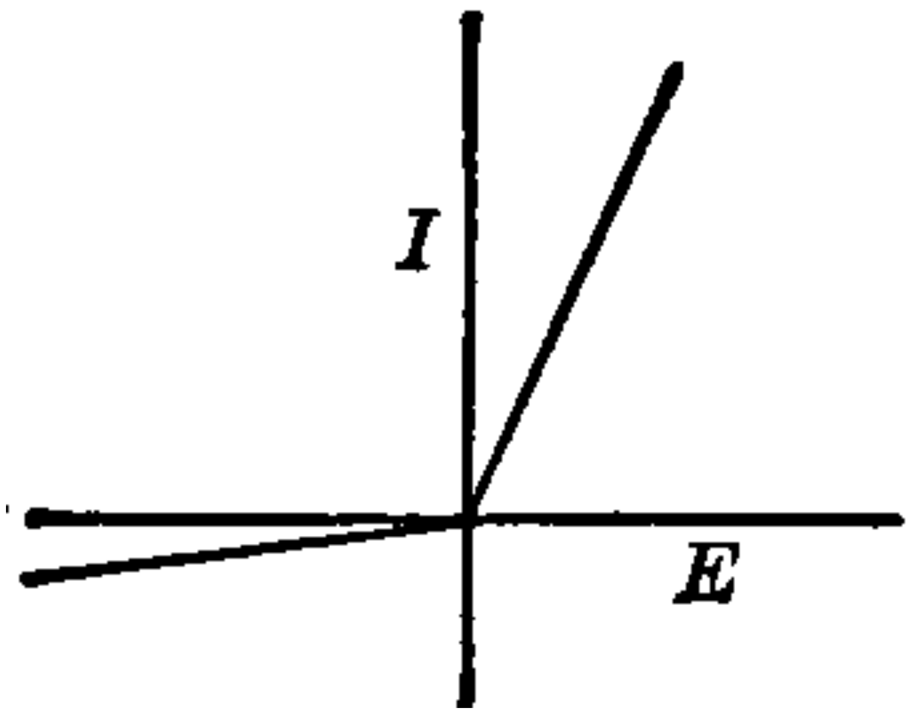

FIG. 801.

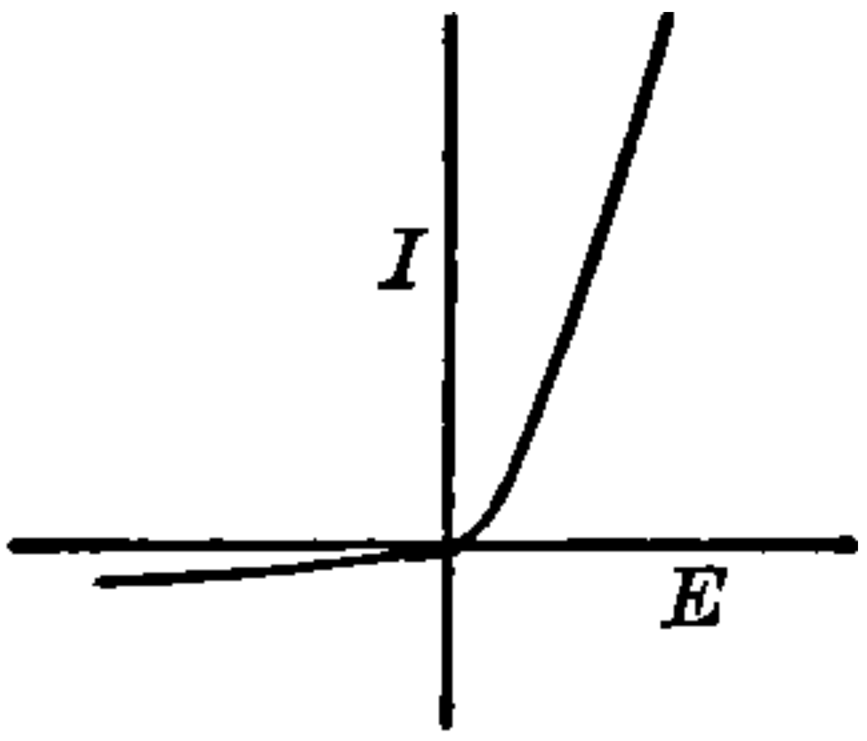

FIG. 802.

Consider a detector of the above type connected at D in Fig. 803. AC is a generator of *radio frequency* alternating current, and T a transformer. Assume the voltage supplied by the generator to be that shown in Fig. 804(a), then the current which flows through the detector will be similar to that shown in Fig. 804(b). The small reverse current is that due to the leakage. Due to the inductance

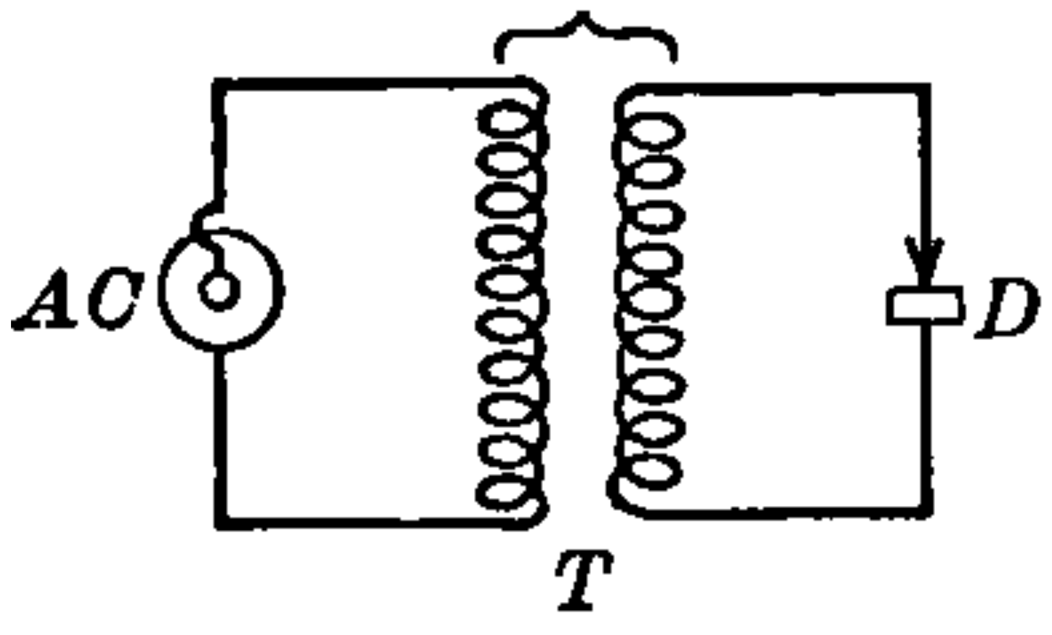

FIG. 803.

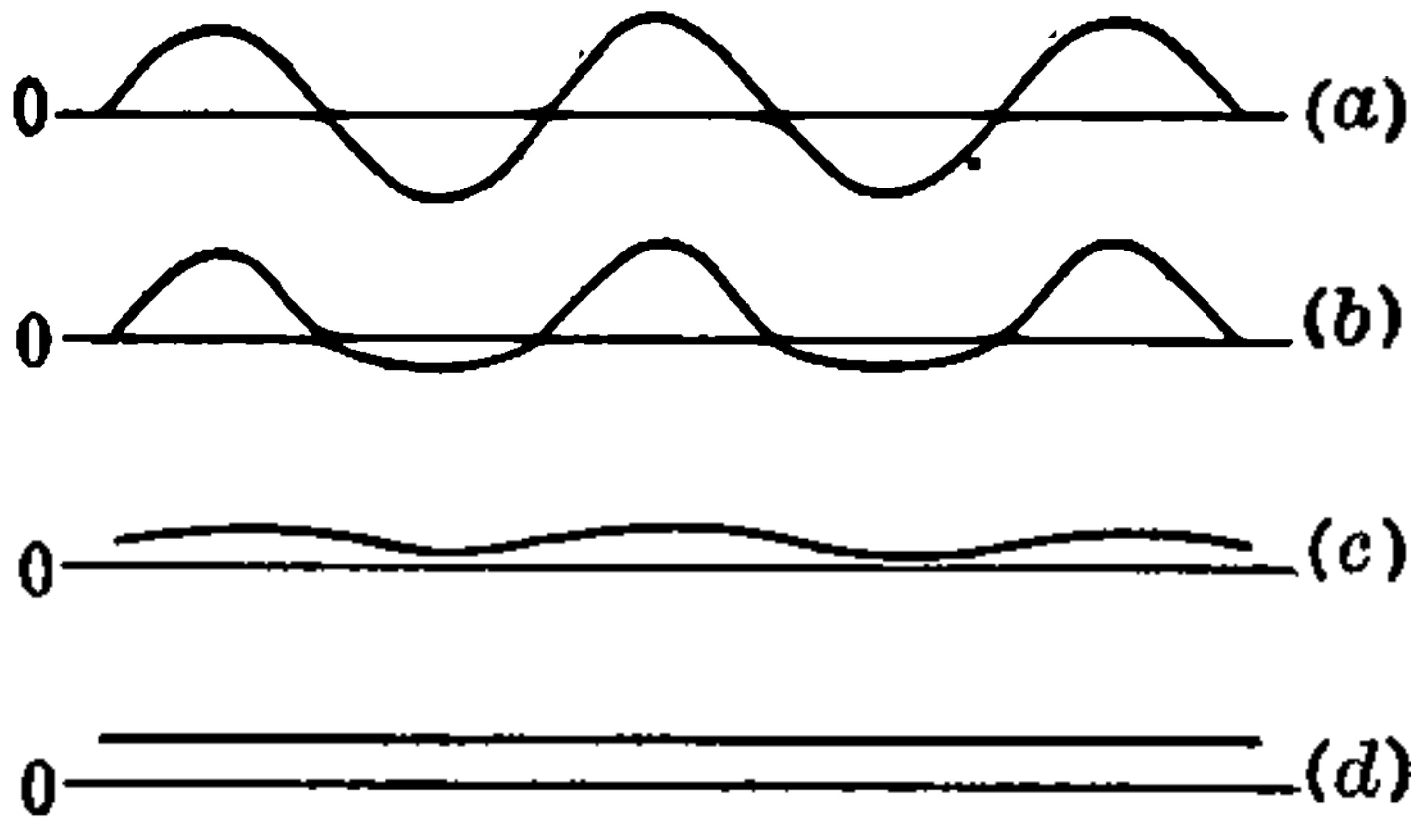

FIG. 804.

of a telephone winding, a current such as 804(*b*) could be passed through a telephone only with great difficulty, and as explained before, would accomplish no useful purpose (due to the fact that it has a radio frequency, not audible to the ear) even if it could pass through the winding. The result of connecting a telephone directly in series with *D* would be a current through the telephone of the nature shown in 804(*c*). This is a practically steady unidirectional current much smaller than the average value of 804(*b*). The current is smaller because the telephone offers a high impedance to the A. C. going to *D*. The current is nearly steady because the inductance of the phones has a great tendency to keep the current from varying and is assisted in this steadying action by the stray capacitance, in parallel with the phones, between the wires of the circuit. This capacitance, although very small, is sufficient to store the greater part of the peaks of the pulses of current long enough to discharge them through the telephone while the detector current is small, or reversed.

Fig. 805 shows a practical variation of Fig. 803. Here the condenser *C* serves two purposes. In the first place it provides a path around the phones which has low impedance for the radio frequency. This permits the A. C. to get to the detector readily. In the second place it supplements the stray capacitance of the circuit in its action of storing the pulses of current. With this connection the current would be steady, as shown in Fig. 804(*d*), and would have a value approximately equal to the average of 804(*b*).

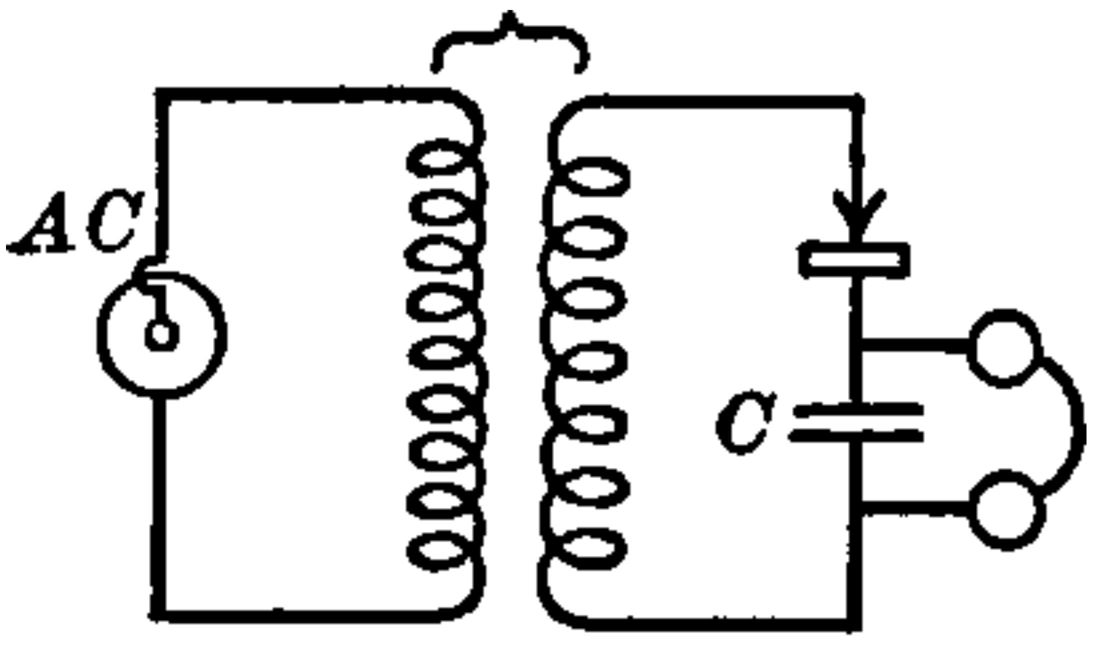

FIG. 805.

From the preceding paragraph it is seen that an unvarying amount of radio frequency power supplied to a detector circuit can produce a steady unidirectional (D. C.) current through the phones. Although this steady power supply and steady current will not produce a sound in the phones, it is a relatively simple matter to arrange some part of the transmitting or receiving system so that the radio frequency power applied to the detector will vary at an audio frequency. The unidirectional current will then vary in a manner similar to the variations of power, and a sound will be produced in the phones by the varying pull on the diaphragm.

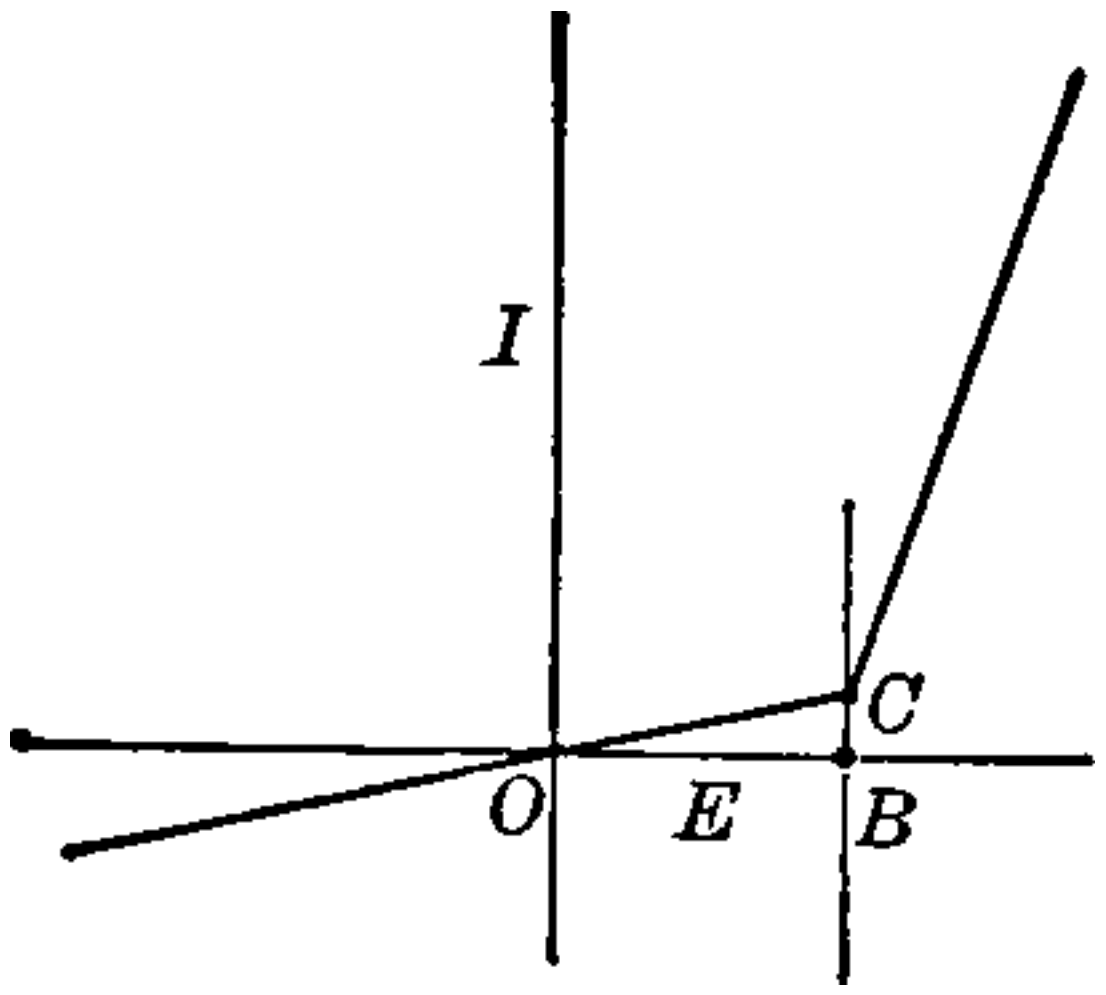

FIG. 806A.

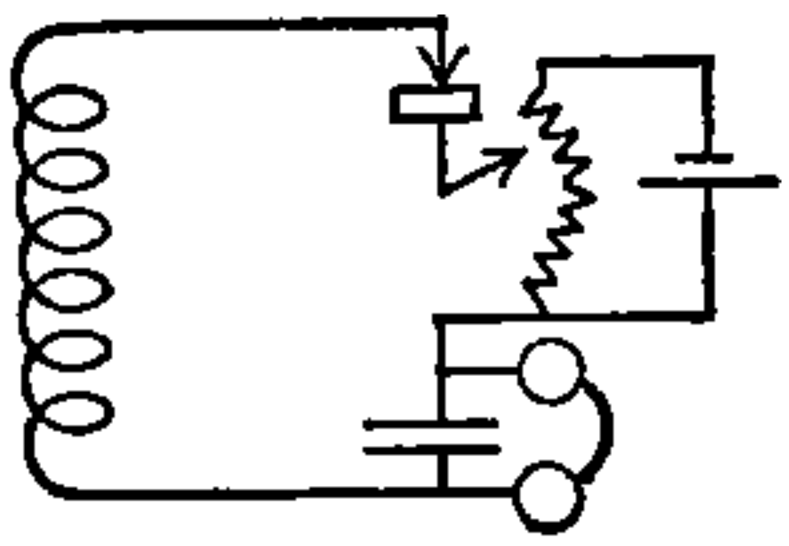

FIG. 806B.

The only modification of the simple check valve action explained above that it will be necessary to consider, is that due to a device which gives a current flow of the type shown in Fig. 806A. It is immediately seen from this curve that an A. C. voltage of maximum value less than *OB* encounters only a high resistance with no check valve action. The electrical action with this small voltage is simply that of a high resistance. Considering a mechanical analogue, it may be said that this device acts as a leaky check valve with a spring tending to hold it shut. The action of this

commonly called a crystal detector. The contact is made between two pieces of mineral or crystal, or between one of the preceding and a metal contact. Examples of such detectors are a blunt metal point in contact with a carborundum crystal, a sharp metal point in contact with a piece of silicon, or a piece of zincite (ZnO) in contact with a piece of chalcopyrite (FeS + CuS). It is a peculiarity of crystal detectors that some points of contact are much more sensitive than others, so that it is necessary to find a sensitive contact *by trial,* while receiving electrical impulses (from a local buzzer, if necessary). The chief advantage of this type of detector is simplicity. Probably the most serious disadvantage is the ease with which the crystal detector may be caused to lose its sensitive adjustment. Either a mechanical jar, or a strong electrical impulse is apt to destroy the sensitiveness of the point of contact so that no signals will be received until a new sensitive point of contact is found by trial.

It will be seen by referring to the curves of Fig. 502 that a two-element vacuum tube may be used as a detector acting in the manner described above. This tube, known as the Fleming Valve, has been used as a detector, but since the invention of the three-element vacuum tube it has dropped out of use.

Fig. 504 shows that in the three-element vacuum tube the variation of current with variation of voltage is similar to Fig. 808, so that it is evident that this tube may be used as a detector in the way explained above. As the currents in the plate and in the grid circuits both vary in about the same manner, the action in either one may be made use of. As a detector, the three-element vacuum tube has several advantages. In the first place, its action is very stable.

No ordinary mechanical or electrical shock affects the action of the tube as a detector, after the shock has passed. In the second place, by utilizing the amplifying action of the tube the energy available to produce signals may be increased, thus giving louder signals, and at the same time aiding sharp tuning of the oscillating circuits by taking but very little energy from them. A further advantage is due to the ability of the tube to generate radio frequency alternating current (undamped oscillations). This advantage will be explained later. Practically, the connections used for this tube as a detector are always such as to utilize the amplifying action of the tube to some extent. From this it follows that the incoming signals are always applied to the tube so as to produce a change in the voltage between the grid and filament, this being the input connection for the tube used as an amplifier. The phones are always connected to the plate circuit.

The circuit shown in Fig. 809 makes use of the possibility of detector action in the *grid* circuit. The condenser C_g prevents any free flow of electrons between the filament and grid, outside of the tube. The high resistance grid leak R provides a current path which tends to bring the grid, more or less gradually, to the same potential as the point to which R is connected. In some tubes the leakage which takes place inside of the tube is large enough so that it is not necessary to provide the leak R on the outside of the tube. This is particularly apt to be the case with tubes which have traces of gas left in them.

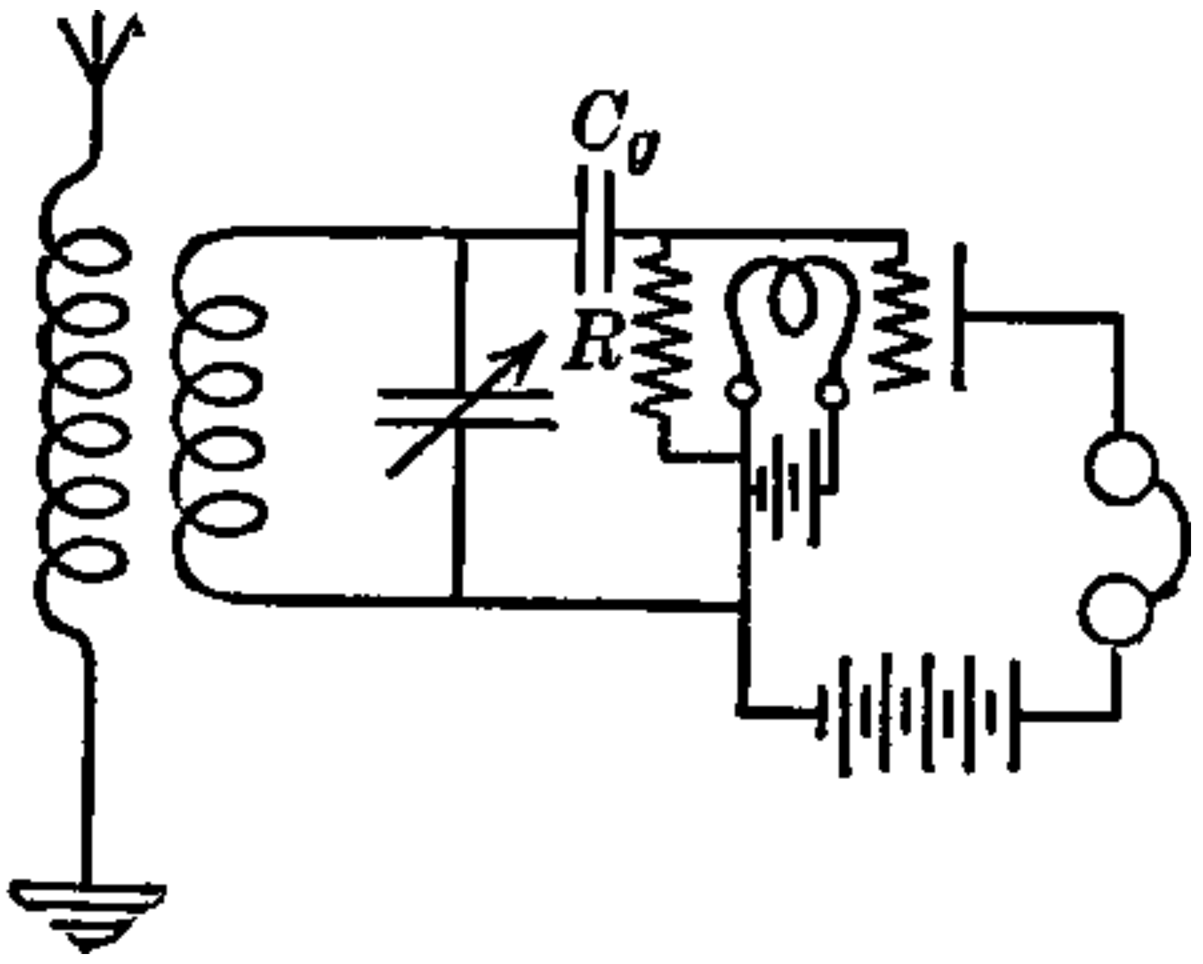

FIG. 809.

If an undamped oscillation is supplied to the grid through the condenser C_g, due to the check valve action in the grid circuit, current will flow through the tube away from the grid. As the current flows *away* from the grid without a free supply of current to the grid, the potential of the grid will fall, making it negative with respect to the filament. As it becomes negative the flow of current through the leak increases, and very soon a grid voltage is reached such that the current flowing to the grid through the leak is just equal to the current flowing away from the grid through the tube. As long as the radio frequency power supplied remains constant the balance will be maintained at this particular grid voltage. If the power supply increases a greater current will flow away from the grid, through the tube, and the grid voltage will drop to a lower value for its new condition of equilibrium. If the power supply decreases, or stops, the grid potential will go back toward its original value, so that the negative voltage on the grid changes in proportion to the radio frequency power supplied to the tube. This change in the *average* value of the grid voltage causes a corresponding change in the plate current, and, consequently, a change in the pull on the telephone diaphragm. If the power supplied changes at an audio frequency an audible sound is produced in the phones. The action of this circuit in the particular case of receiving a damped wave sent out by a spark set is shown in Fig. 810. Fig. 810(*a*) represents the voltage received. Fig. 810(*b*) represents the corresponding grid potential. Fig. 810(*c*) represents the plate current, and Fig. 810(*d*) represents the smoothed out current which flows through the phones. It is seen that the detecting action takes place in the grid circuit, and that the resulting audio frequency changes are

age in the circuit correspond to the point of sharpest curvature of the plate current curve. This is the steady value of D. C. necessary in the second of the preceding elementary cases (see Fig. 806A). When a constant radio frequency voltage is applied to the grid the plate current varies approximately as shown in Fig. 807. The increase of current above the steady value being much greater than the decrease below the steady value, the *average* value of the plate current *increases.* This increase is proportional to the radio frequency power supplied to the circuit. As before, changes in the supplied radio frequency power will cause corresponding changes in the telephone current, and sounds will be produced in the phones by audio frequency changes of the power supplied. The action of this circuit in the particular case of receiving a damped wave sent out by a spark set is shown in Fig. 812. Fig. 812(*a*) shows the received voltage. Fig. 812(*b*) presents the corresponding values of plate current, and Fig. 812(*c*) shows the current through the telephones. In the circuit of Fig. 811 the amplifying action of the tube is utilized before the detecting action takes place.

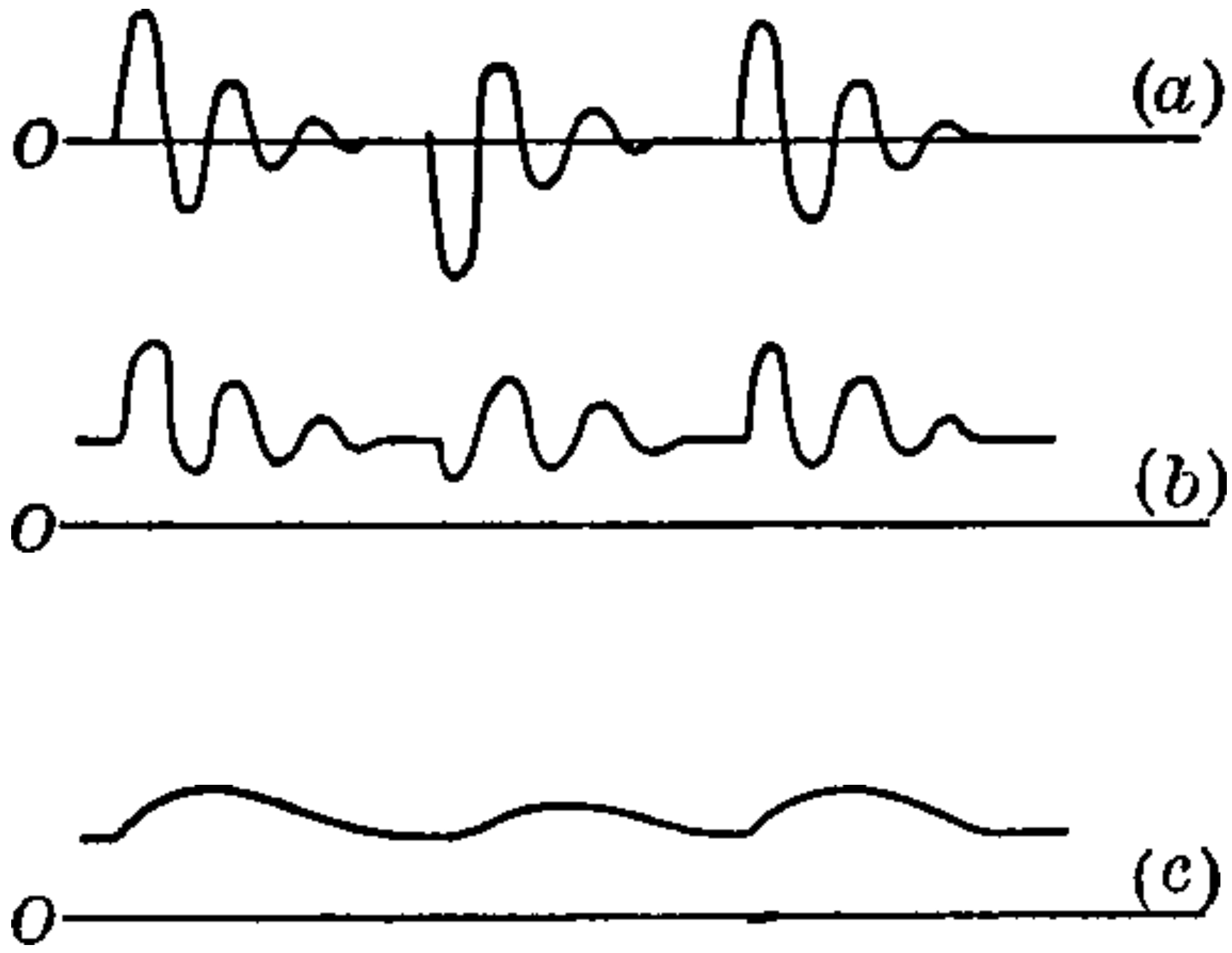

FIG. 812.

Aside from the fact that the detecting action takes place in the grid circuit of one, and in the plate circuit of the other, there is an important difference between the circuits of Figs. 810 and 812. The circuit of Fig. 810, *with* the grid condenser, gives a certain amount of cumulative effect. That is, the charge accumulated in the grid condenser by one cycle of radio frequency does not all leak away until a number of cycles have passed. The result of this is that at any instant the accumulated charge in the grid condenser (and consequently the potential of the grid) is due to the cumulative effect of several preceding cycles of the radio frequency. This causes the changes of plate current obtained (for a given change in radio frequency input) to be greater than the changes of plate current obtained in circuits not using the grid condenser. The final result is that circuits with the grid condenser are usually more sensitive detectors than those without.

As the preceding detectors produce sounds in the phones only when the power applied varies at an audio frequency, they will not give a signal with any of the undamped wave systems unless some device is provided *at the receiving station* to vary the input to the detector. Devices which make this change by interrupting one of the receiving circuits, by changing the resistance of some part of the receiving circuit (as by a sliding contact) or by changing the tuning of some part of the receiving circuit are of the simplest type. These changes must, of course, be made at an audio frequency.

Another method of producing variations of the radio frequency applied to the detector makes use of a low-power, undamped wave generating set *at the receiving station.* The steady undamped oscillations produced by the local source are combined with the incoming oscillations, and the resultant is applied to the detector. If the frequency of the local oscillation is made slightly different from that of the incoming signal, at one instant the two oscillations will oppose each other, and an instant later they will add to each other.

The result is that the radio frequency power contained in the resultant varies. If N represent the frequency of the incoming wave, and the local frequency is made equal to $N+1000$, the locally generated wave will overtake the incoming wave 1000 times per second. The power applied to the detector will vary at a frequency of 1000 per second, and a sound will be produced in the phones with this frequency. If the local frequency is made equal to $N-1000$, the incoming wave will overtake the local one 1000 times per second, and the result will be the same as before. It will be seen from this that the sound produced in the phones has a frequency equal to the difference between the received frequency and the local frequency. This method of receiving undamped wave signals is called heterodyne reception. It is also referred to as "beat reception," due to its depending upon the beats between two slightly different radio frequencies.

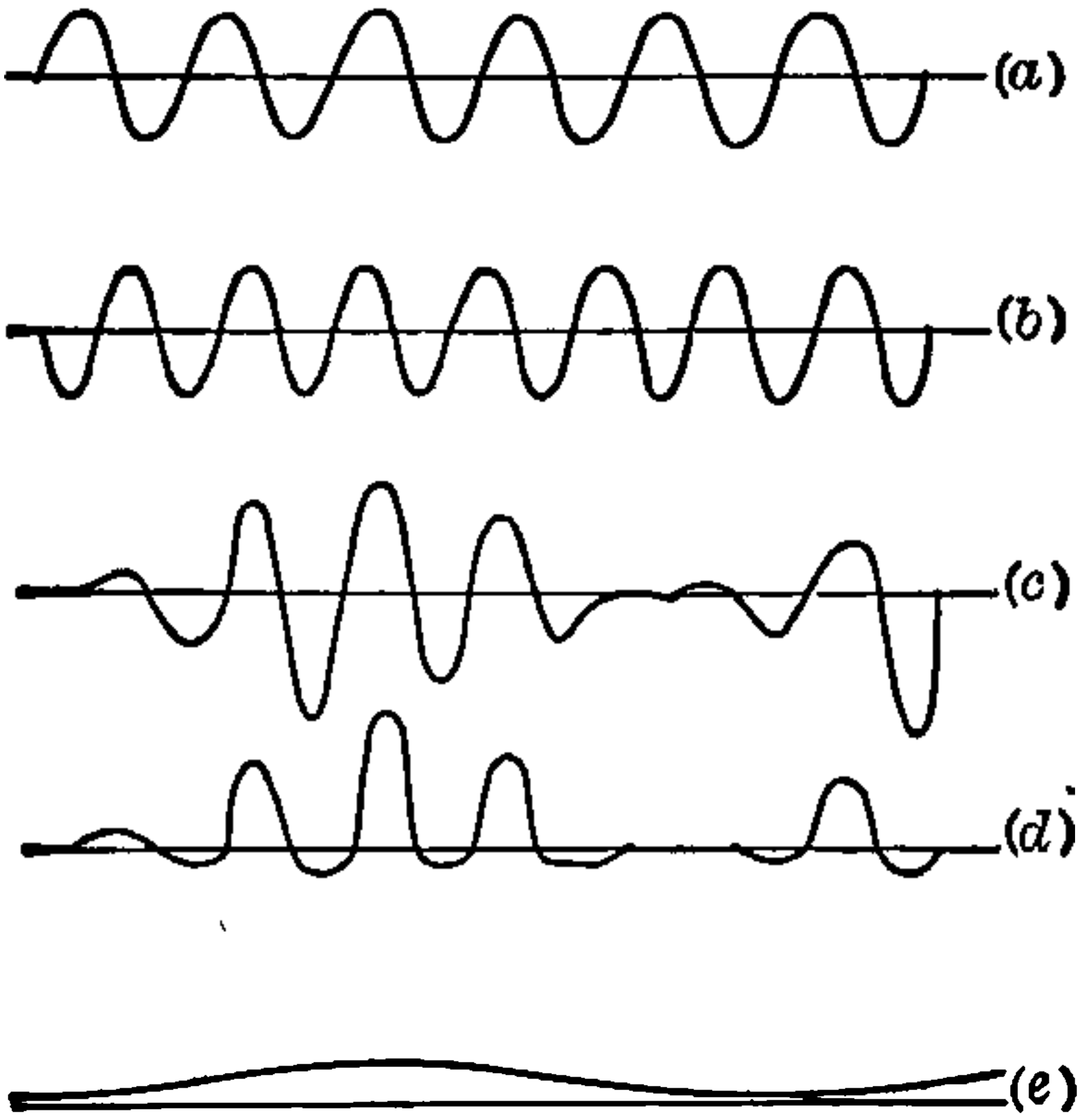

FIG. 813.

of producing so-called "regenerative amplification" in addition to its other actions. This regenerative action consists of taking part of the output of the detector and feeding it back into the input with the received signal. This increases * the strength of the audible signal produced. Its action will be discussed more fully in the following chapter. One disadvantage of the autodyne is, that since it is acting as a generator and a detector at the same time, it cannot act to the best of its ability as either. Another disadvantage is due to the necessity of producing "beats." To produce these beats the generator circuit of the detector must be tuned to a wave length different from the one being received. Under this condition, the generator circuit is *not* in resonance with the received wave. As the generator circuit of the autodyne is also the detector circuit, the detector loses somewhat by being operated slightly out of resonance with the received wave. This disadvantage is of no importance with short waves, but becomes appreciable with long waves. An autodyne detector used in connection with a radio frequency amplifier also presents special difficulties. These disadvantages may be avoided by the use of heterodyne reception.

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* The increase due to regeneration is found to be very small compared to that due to the heterodyne action.

CHAPTER IX.

RECEIVING CIRCUITS.

A receiving circuit consists primarily of a device to be acted upon by the electromagnetic waves, a detector, and suitable connections between these two. The part upon which the electromagnetic waves act is ordinarily called an antenna, or aerial. The antenna or aerial consists of one or more wires elevated above the ground and insulated from it at all points except where it is connected to ground through the receiving circuits. Wires buried a short distance under ground, or under water, or wires without a ground * may be used for this purpose. The buried wires are thoroughly insulated. A closed loop or coil may also be used to pick up the effects of the electromagnetic waves. This application will be explained in Chapter XI.

So far as the production of oscillations is concerned, the antenna acts in the same manner as the closed oscillating circuit. The inductance of the antenna circuit is partly that of the antenna itself (due to the flux set up around the wire by the current flowing in it) and partly that of one or more coils connected in series with the antenna. The capacitance of the circuit in the simplest case is entirely due to the antenna. This antenna capacitance consists of the electrostatic capacity between the wires of the antenna on one side and the ground on the other side.

The advancing electromagnetic waves produce in the antenna a voltage similar to the voltage at the transmitting station in all respects except size. The magnitude of this received voltage depends upon the receiving antenna and

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* The type without a ground connection usually has the receiving apparatus near the middle.

the amount of power picked up by the receiving antenna. In any case, both the power and voltage at the receiving end are extremely small fractions of the corresponding quantities at the transmitting station. With a given antenna, in order to pick up the maximum amount of power from the electromagnetic waves, the antenna must be tuned to the wave length being received. The variation in the effects in the antenna circuit when its constants are varied are exactly the same as the variation in a closed oscillating circuit when the same changes are made,* the maximum effects being obtained when the antenna circuit is so tuned that it tends to oscillate at the same wave length as the incoming wave.

The simplest tuned receiving circuit is shown in Fig. 901. Here the inductance L is made just large enough to bring the antenna to resonance with the wave length being received. A circuit such as this responds to received signals of equal strength but of different wave length with a strength which depends upon the decrement of the antenna circuit and of the received signal, and upon the difference between the received wave length and the wave length to which the antenna is resonant. If the sum of the decrements of the antenna system and of the received wave is small, the strength of the signal will fall off very rapidly as the *resonant* wave length of the antenna is made different from that of the incoming wave. On the other

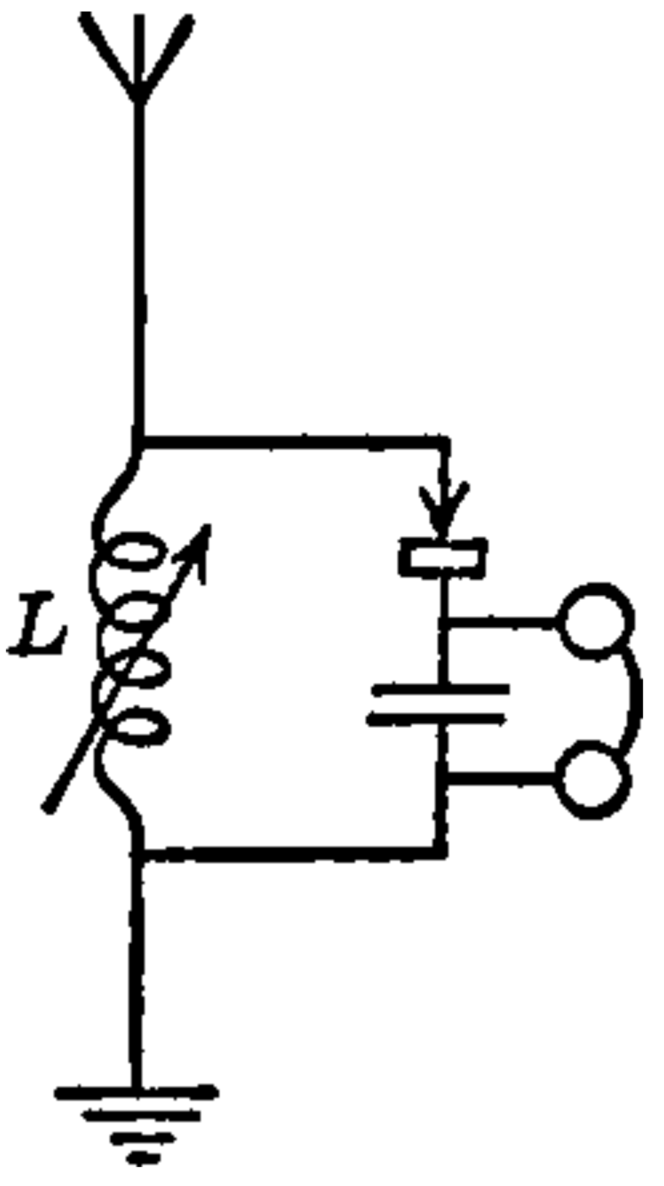

FIG. 901.

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* This neglects the fact that any circuit having all or part of its inductance and capacitance *distributed* has a series of natural frequencies, or frequencies of resonance. The preceding statement applies to the lowest frequency, which is the only one used.

of energy stored in the antenna circuit with a given current is higher than before, while the losses (due to the resistance) are not appreciably changed, for the added resistance is very small. The action here is very much like starting a loaded swing into motion. If the load is light, a few pushes will bring the swing to its maximum motion, and it will not make very much difference whether the pushes are timed just right or not. This corresponds to the simple antenna. If additional load is added to the swing the rate at which it swings back and forth does not change, for the force tending to return it to its vertical position increases just exactly as fast as the mass to be moved increases. However, with the additional load, it will take a larger number of pushes to get the swing going with the same motion that it had in the preceding case. Also, the pushes will now have to be timed just about right or but little result will be produced on the motion of the swing. This decrease of decrement could also have been predicted from the formula for decrement in terms of the inductance and resistance. $\delta = \pi R/\omega L$. As L has been greatly increased while R has been increased only slightly, a decrease in δ necessarily follows. (ω was kept constant in this case.)

Decreasing the decrement of the antenna circuit serves the purpose of making the tuning sharper, so that wave lengths materially different from the one being received will not interfere with receiving. The nature of the change can be seen from the resonance curves of Fig. 903. Here the abscissæ represent the wave lengths being received, and the ordinates represent the corresponding intensity of signal produced. (The strength of the electromagnetic waves

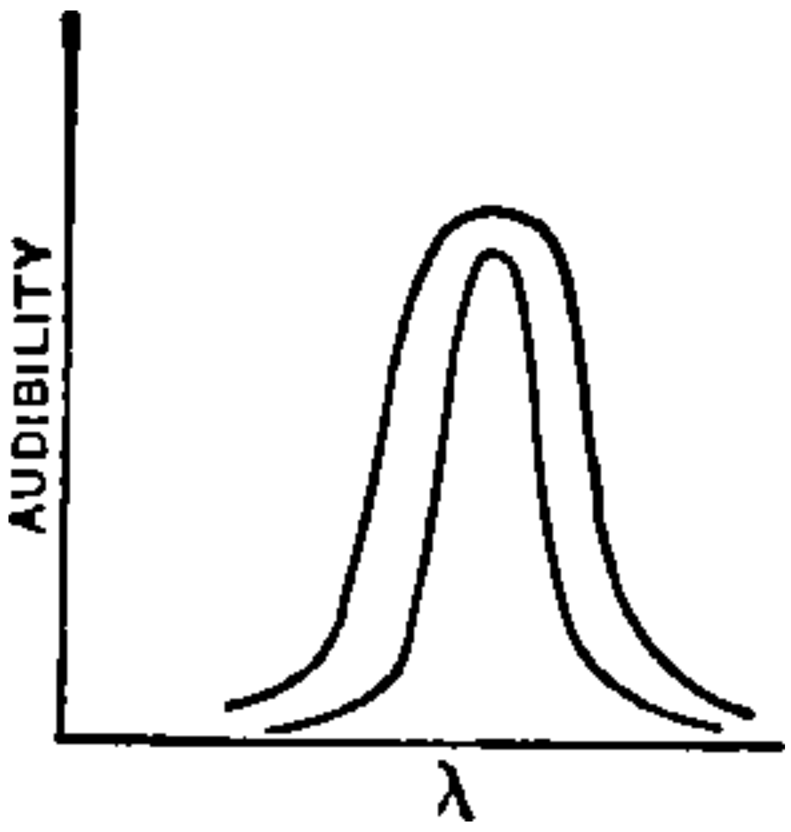

FIG. 903.

remaining constant.) The maximum intensity of signal occurs when the wave length received is the same as the wave length at which the antenna tends to oscillate.

In order to get the loudest possible signal from a given antenna, a given detector, and an electromagnetic wave of constant strength, the energy received by the circuit should be divided about equally between the detector and the rest of the circuit.* This division may be controlled by inserting a transformer between the antenna circuit and a separate circuit containing the detector. By means of this transformer the voltage impressed on the detector may be varied (as compared with the voltage existing in the antenna) until the best results are obtained.

In order to get sharp tuning the power used by the entire receiving system should be as small as possible. In this case the power used by the detector must be kept as low as the necessary strength of signal will permit. A transformer between the antenna circuit and a separate circuit containing the detector may be so arranged as to accomplish this also.

It is seen from the two preceding paragraphs that the requirements for obtaining two desirable conditions in receiving apparatus are exactly opposed to each other, but both of these requirements are met by the same device (with different adjustments, of course). The result is that this device (a transformer or its equivalent, technically called a coupler) is practically always used and that a compromise is then made between the conflicting requirements. If interference is not present, use may be made of the maximum signal obtainable, with the resultant lack of sharp tuning. On the other hand, in the presence of inter-

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* See Zenneck "Wireless Telegraphy," Par. 172.

ference, the energy taken by the detector will be decreased to decrease the decrement, thus giving sharper tuning. Naturally, to be received in the presence of interference, a signal has to be stronger than would be required if the interference were not present.

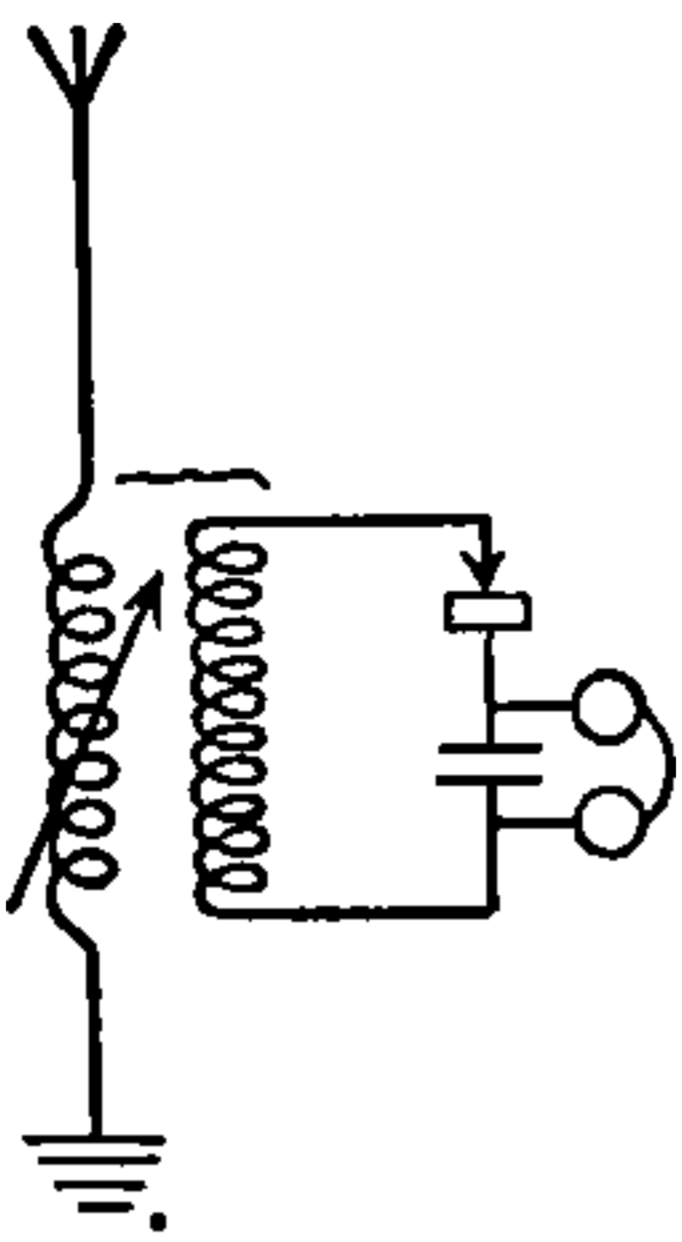

FIG. 904.

Fig. 904 shows the simplest circuit containing a transformer as described in the preceding paragraph. This is called an untuned circuit. This circuit in the untuned form has about the same advantages and disadvantages as the circuit of Fig. 901.

To utilize the secondary circuit to the best advantage it is necesary to tune the secondary as well as the primary. The circuit then becomes that of Fig. 905. A variable condenser is usually used for C_2. L_2 also is made variable either by cutting out part of the coil, or by using a variometer. It may be well to remember that there is always the capacitance of the coil and some stray capacitance between the connections to the coil in addition to the capacitance of the condenser. For this reason the wave length of the secondary system does not approach zero as the capacitance of the variable condenser does. That is, *with any particular inductance,* there is some wave length (somewhat greater than the fundamental wave length of the coil) below which it is impossible to tune.

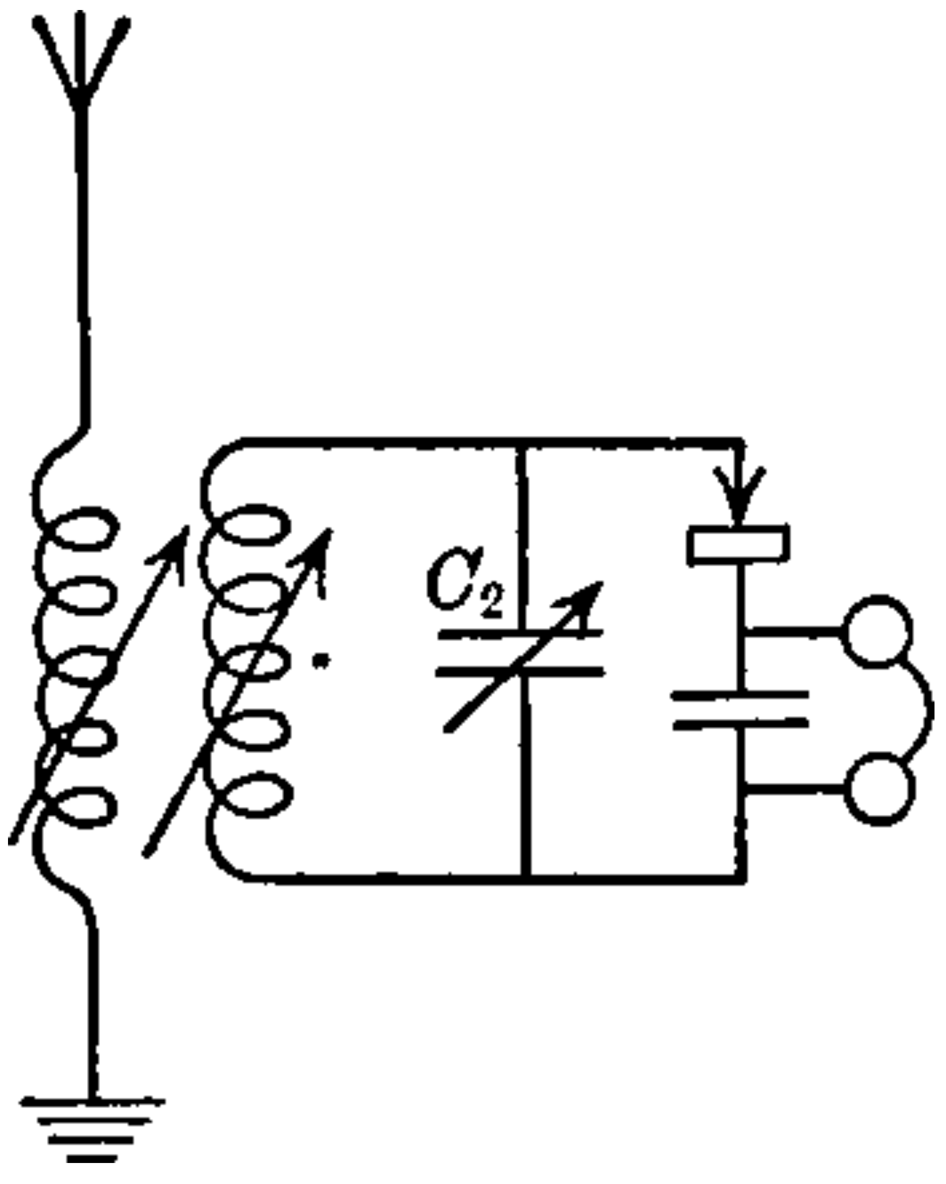

FIG. 905.

been tuned to a wave length near that to be received.) After getting an audible signal the secondary will be tuned, the coupling adjusted to give best results, and finally fine adjustment made on the primary (antenna). The best value of coupling, as indicated above, is usually determined as a compromise between some medium value (which will give the loudest signal) and very loose coupling, which tends to eliminate interference, but at the same time weakens the signal.

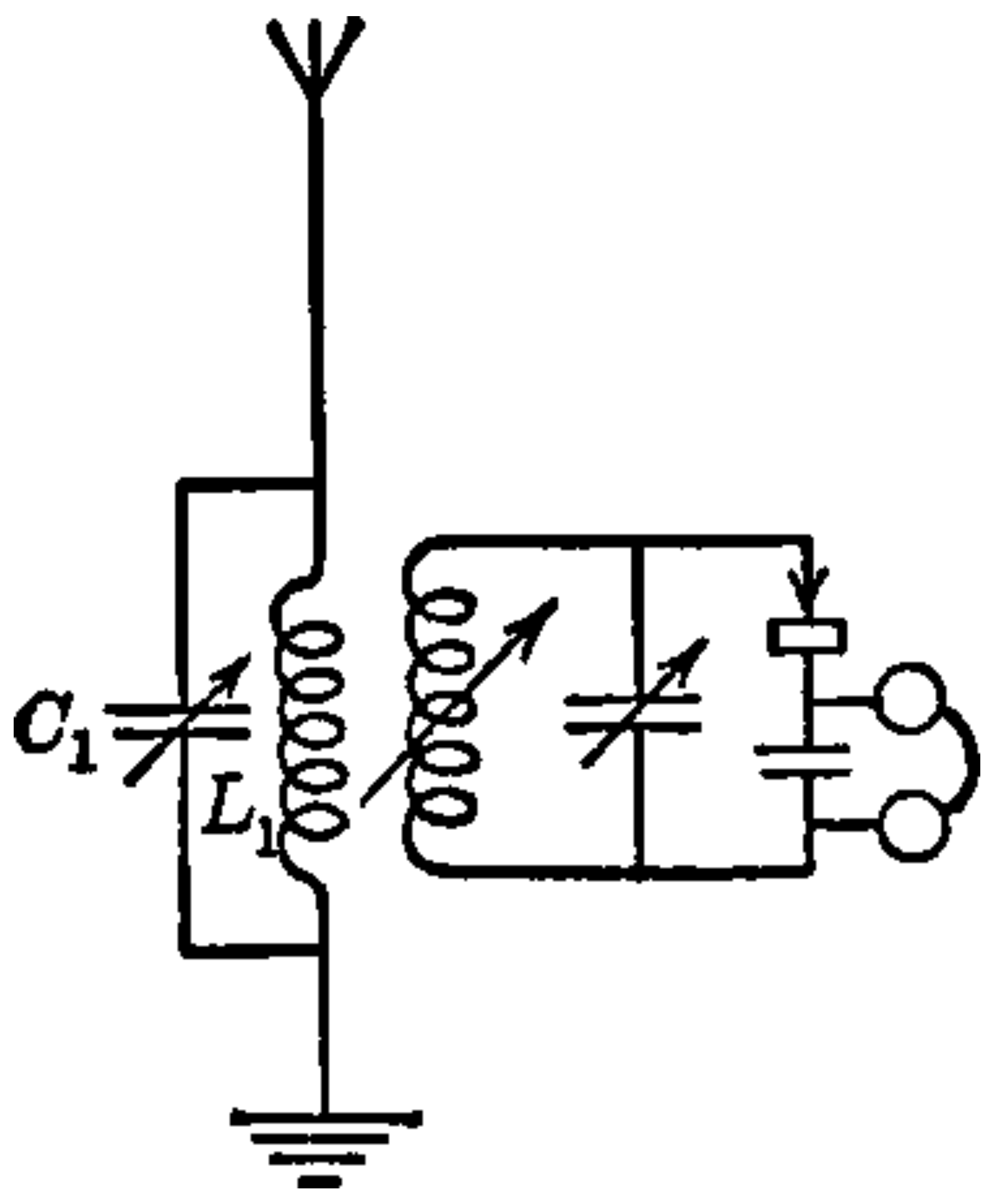

FIG. 906.

A slight modification of the circuit of Fig. 905 is shown in Fig. 906. Here condenser C_1 is connected around the added inductance of the antenna circuit. This condenser is practically in parallel with the capacitance of the antenna so that increasing its value increases the wave length to which the antenna is tuned. Unless inductance L_1 is small (say less than four times the inductance of the antenna) the wave length of the antenna circuit may be computed assuming the condenser C_1 to be in parallel with the capacitance of the antenna. The advantage of this circuit is that it is *not* necessary to make the inductance L_1 continuously variable or variable by *small* steps. L_1 will be made variable only by a few large steps, all of the fine variations of wave length being made by the condenser C_1. A further advantage in circuits for long waves is that the use of C_1 reduces the amount of inductance required to tune for a given wave length. The disadvantage of using C_1 is that the addition of the condenser increases the decrement of the circuit. This increase in decrement is due to the additional losses in the coil caused by current which circulates around through L_1C_1. As long as C_1 is not much greater than the capacitance of the antenna this increase in decrement is not serious, the increased ease of manipulation of the circuit offsetting the increase in decrement.

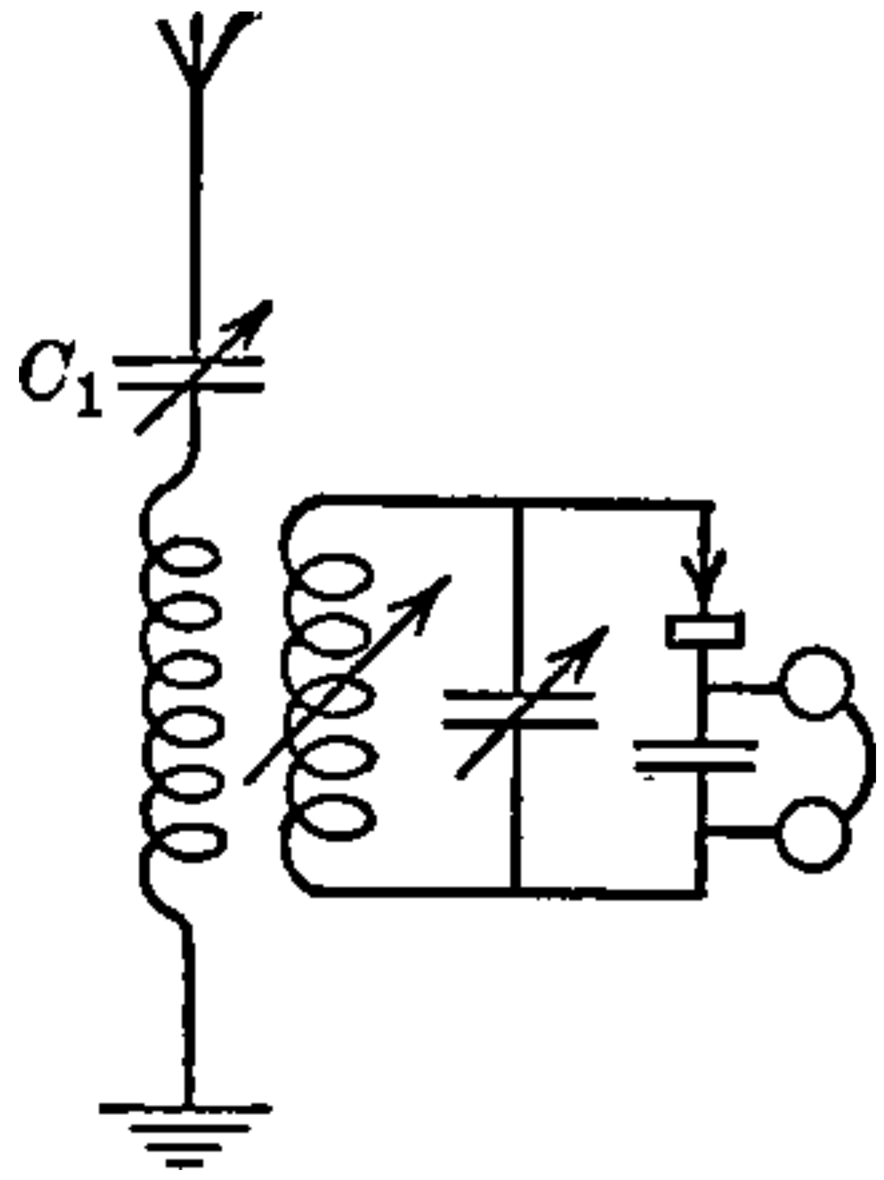

FIG. 907.

In the two preceding circuits it has been assumed that the wave length to be received is longer than the fundamental wave length of the antenna. If this is not true, a modification of the antenna circuit, such as that shown in Fig. 907, becomes necessary. Here the condenser C_1 is inserted in series with the antenna circuit, and is, therefore, in series with the antenna capacitance. The result is that the total effective capacitance of the antenna circuit in this case is less than that of the antenna alone. This decrease in the effective capacitance of the antenna reduces the wave length to which the circuit is resonant. A practical limit to this reduction is reached when the added capacitance becomes so small that the antenna tends to oscillate as though disconnected from the ground entirely. The wave length in this case is about half the fundamental. In any case, when the added condenser is not very small, the wave length may be computed by using the effective capacitance computed as the result of the added condenser in series with the capacitance of the antenna. This effective capacitance and the total inductance of the antenna circuit substituted in the wave length formula will approximate the value actually obtained. Condenser C_1 in Fig. 907 is known as a short wave condenser. In sets making use of the circuit of Fig. 906, for long waves, this same condenser is used in series with the antenna for short waves. It should be noticed that it is always necessary to have some *added* inductance in these circuits to form the primary of the coupler. This variable series condenser may also be used when its presence is not required on account of short wave lengths. As its insertion necessitates the addition of more inductance to tune for a given wave length, its action is to *decrease* the decrement of the antenna circuit in much the same manner as the circuit of Fig. 902. The advantage of this use is that it retains the ease of adjustment of the variable condenser, makes it unnecessary to have an inductance variable by *small* steps, and decreases the decrement of the antenna circuit.

It is pointed out in the preceding paragraphs that the inductances in a coupler may be changed by cutting out portions of the coils. The simplest arrangement for giving approximately continuous variation of inductance within the limits of the coil is shown in Fig. 908. Here it is seen that the connections are made to the coil by means of contacts which slide on two sets of taps from the winding. One set of taps usually changes the winding by steps of one turn. The other by steps of about 10 turns. Evidently, by using this combination any number of turns from zero up to the full coil can be put into the circuit. An arrangement such as this is

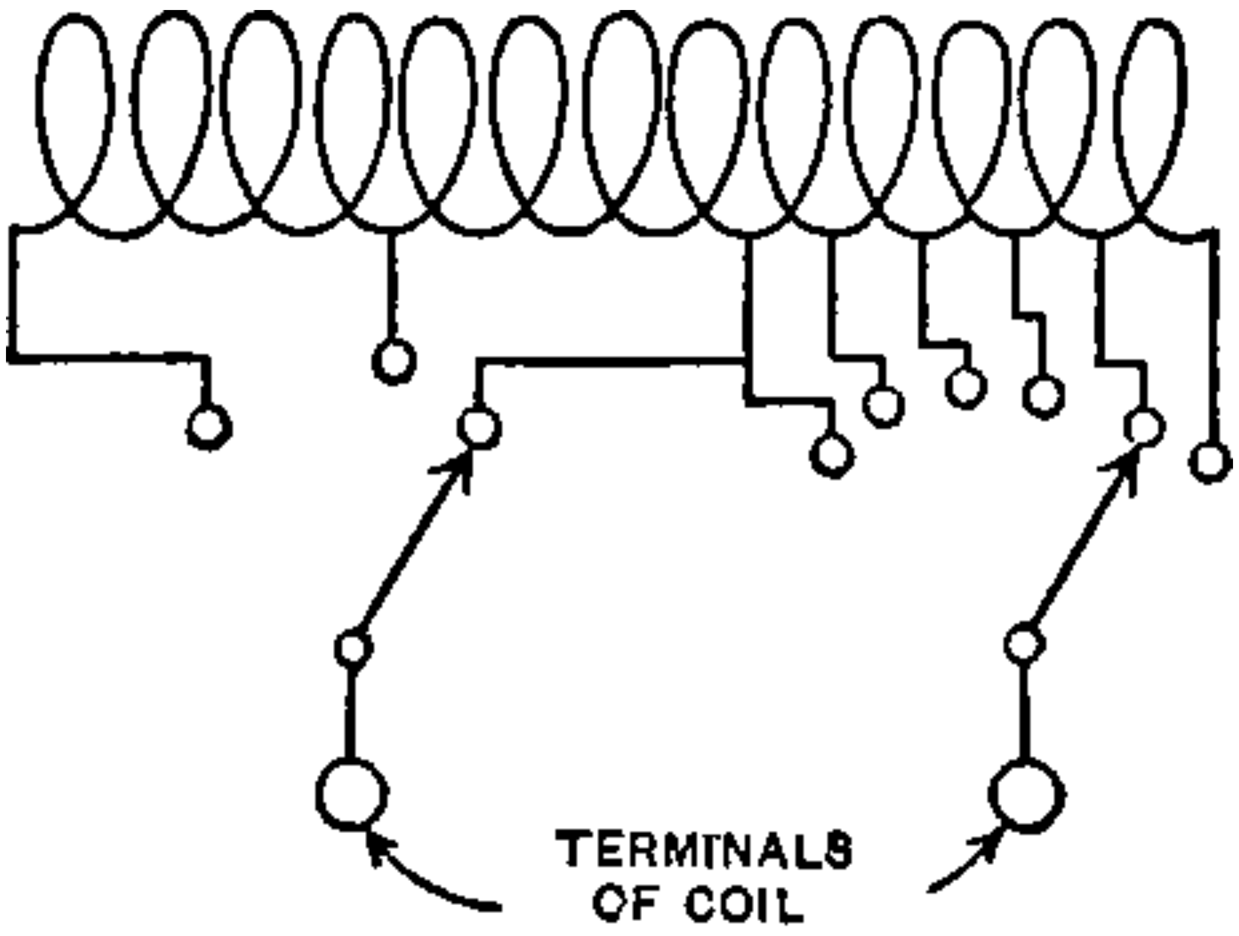

FIG. 908.

ting up of the winding is accomplished by switches, called "dead end switches," which are usually operated automatically by the motion of the sliding contact which changes the portion of the winding in use. Such a circuit is shown in Fig. 909. Another way to prevent the dead end from becoming resonant to the wave lengths in use is to short-circuit it. This is seldom done unless the dead end is a large percentage of the whole coil. In the best sets tests would be made during construction of the first set to determine whether cutting the winding into sections or short-circuiting it gives the best results. The dead end effects discussed above make it evident that very careful design is necessary to produce a receiving set which will operate efficiently over a wide range of wave lengths.

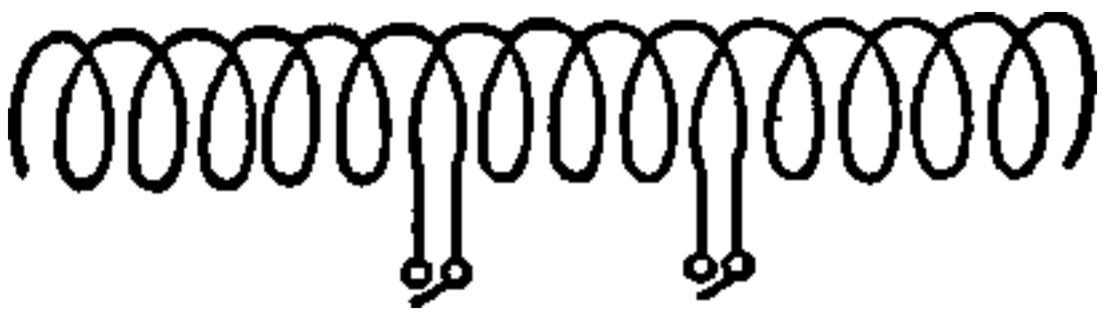

Fig. 909.

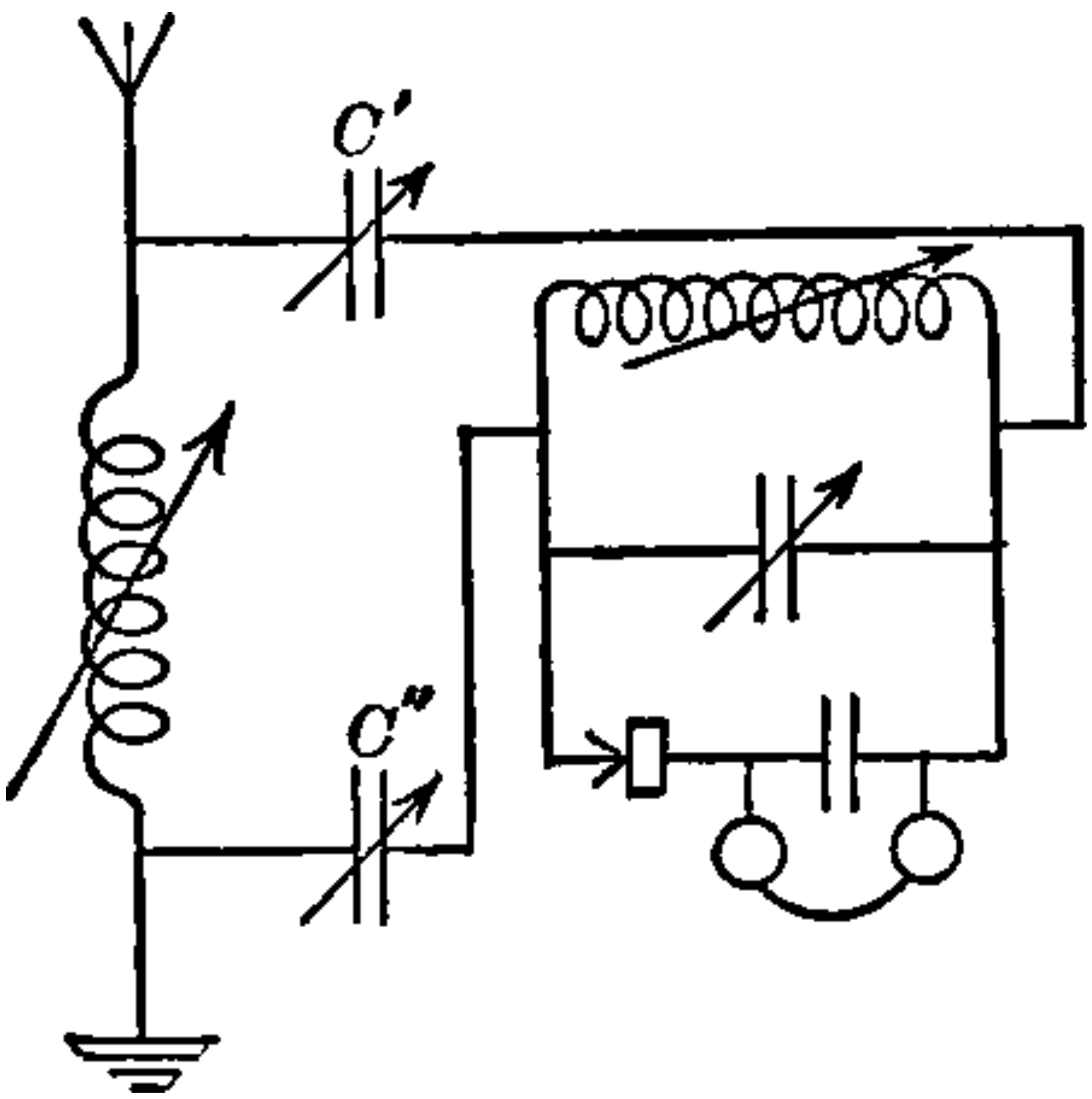

Fig. 910.

Fig. 910 shows a circuit making use of capacitive coupling. In some ways this circuit is exactly the same as that of Fig. 905. In each case there is the antenna circuit, which is tuned to the desired wave length by adding inductance, or inductance and capacitance, and in each case the secondary circuit consists of a closed oscillating circuit. However, the inductance in the secondary circuit is so placed that the flux from the primary winding does *not* produce a voltage in it. The result is that no energy is transferred to the secondary by means of the magnetic field, that is, there is no inductive coupling. The necessary transfer of energy from the primary to the secondary takes place through the condensers *C′* and *C″*. This transfer of energy, and consequently the coupling, is controlled by the capacitance of these condensers. (These condensers are frequently mounted on the same shaft so that they vary simultaneously.) Close coupling is obtained by using large capacitance in *C′* and *C″*. This may be seen by considering the effect of making these condensers very large. They might readily be made so large that their effect upon the radio frequency currents would be negligible. Fig. 910 would then become equivalent to Fig. 911. This shows direct metallic connection of the primary and secondary circuits. It appears from this circuit that with close coupling the voltage applied to the detector will not exceed the voltage existing in the primary inductance. If the detector used is of such construction that it needs power supplied to it with relatively high voltage and small current, this may be a disadvantage. (This disadvantage is not found with the inductively coupled set.) If, with both the primary and secondary tuned exactly to the incoming wave length, the condensers *C′* and *C″* are set for small capacitance, the voltage existing between the ends of the primary coil is split up into three parts, the parts across the coupling condensers and that across the secondary condenser.* This voltage across the secondary being only a

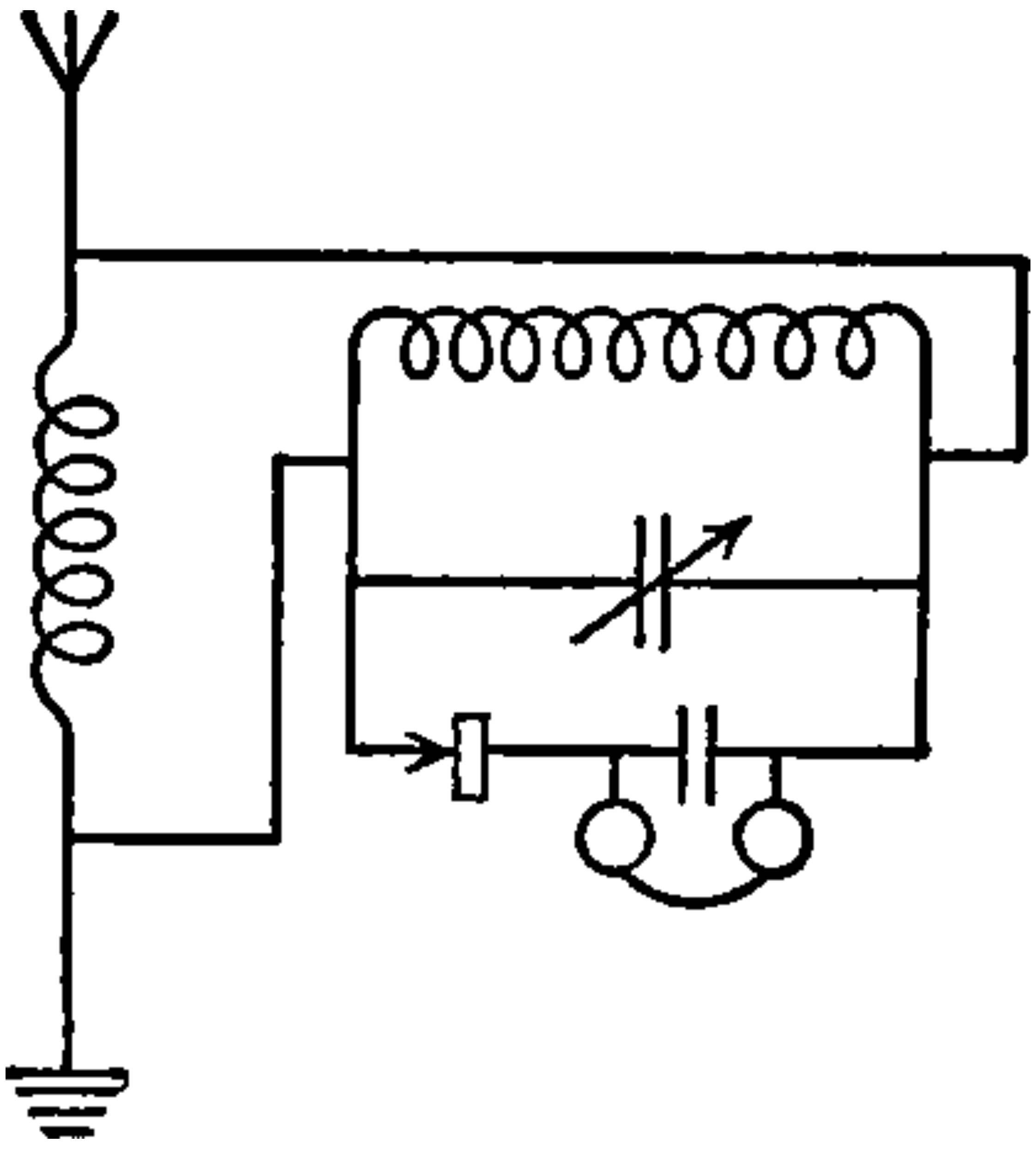

FIG. 911.

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* With the preceding conditions, the parallel circuit will act approximately as a non-inductive resistance, so that the voltage drop across the coupling condensers will be 90° out of phase with that across the secondary circuit.

fraction of that across the primary, the energy is transferred from primary to secondary less rapidly, which means that the coupling is looser. Other arrangements of circuits may be provided to transfer the energy from the primary to the secondary with the aid of condensers. A simple variation of Fig. 910 would short circuit condenser C''. One general advantage of capacitive coupled sets is that they may be made more compact than an inductively coupled set.

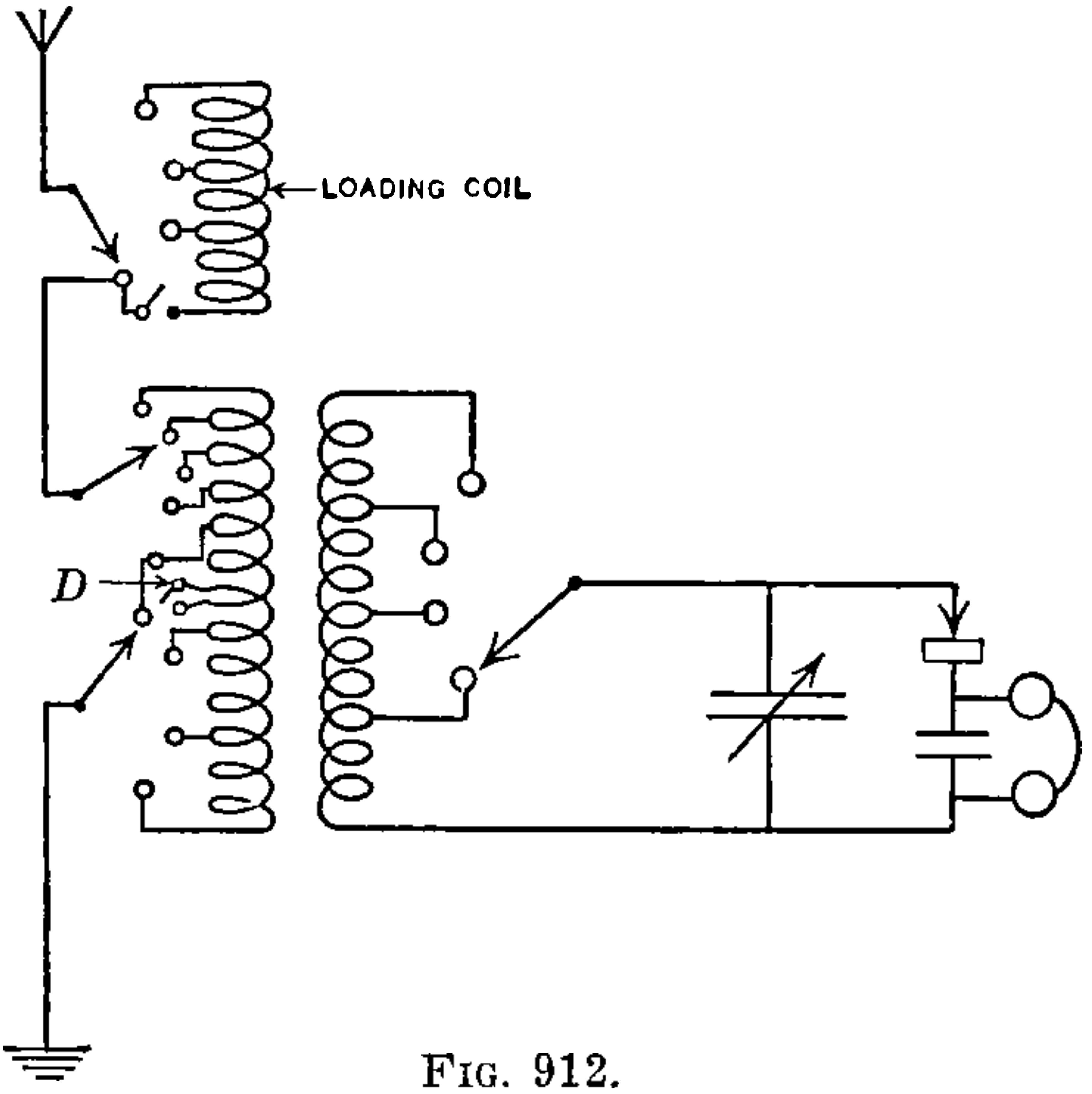

FIG. 912.

A representative receiving circuit, including all of the essential adjustments outlined in the preceding paragraph is shown in Fig. 912 (for an inductively coupled set). The switch marked *D* is a dead end switch, and to get the best results must be opened when short waves are being received. The inductance marked " loading coil " is used only for long waves, which can be tuned to only by the use of more inductance than can conveniently be placed in the primary of the coupler.

terminals *AB,* which opposes the flow of current in the main circuit. For such a circuit to be useful its resistance must be very low, and also the C must be large and the L small, as compared with the effective values in the main circuit. Under these conditions the parallel circuit has practically no effect upon the main circuit so long as the wave length in the main circuit is different from the wave length to which L and C are resonant. On the other hand, if current of the wave length to which L and C are resonant attempts to pass through the main circuit, a relatively very large current (maybe as much as 200 times the main current) is set up in the closed circuit, this circulating current sets up a counter E. M. F. almost equal to the received voltage, and only an extremely small amount of current of this particular wave length succeeds in getting through the main circuit. The application of this circuit to the elimination of *one particular wave length* should immediately be evident. If in the circuit of Fig. 913 the circuit LC is tuned to the wave length of an interfering signal, and then the antenna system as a whole is tuned to the wave length it is desired to receive, interference from the one particular wave length to which LC is tuned will be greatly reduced. Another method of applying the principle of parallel resonance used above is shown in Fig. 914. In this case the circuit LC, instead of being in series with the primary of the coupler, is placed in parallel with it. The action *in* the LC circuit is the same as before, but the effect upon the receiving circuit is much different.

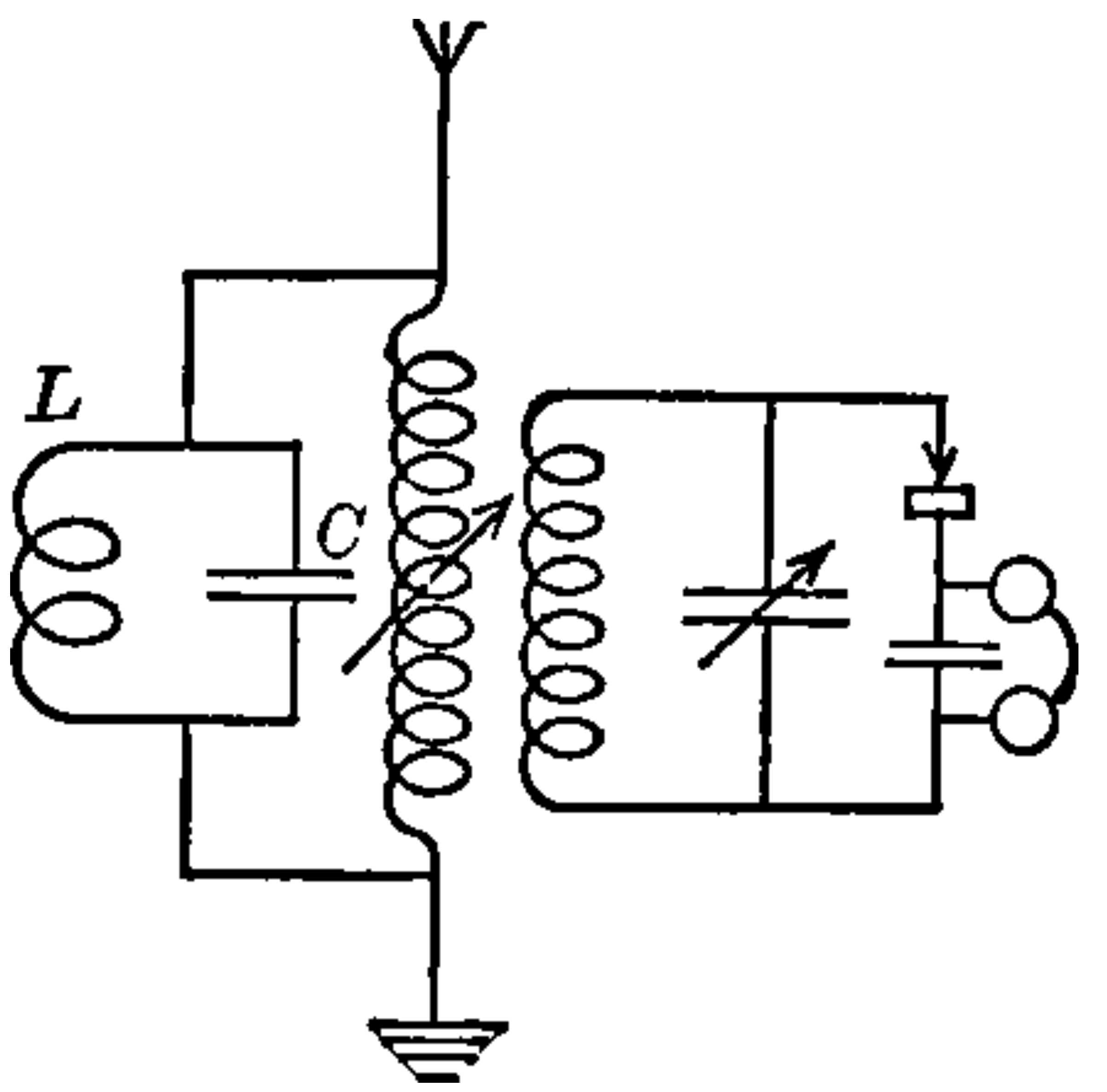

FIG. 914.

Thus it is seen that the coupler will have no appreciable voltage across its primary for any wave length except the one to which *LC* is resonant, for *LC* practically short-circuits the primary of the coupler for other wave lengths. The result of this is that *all* wave lengths except this one are greatly reduced in strength in the primary of the coupler, whereas before only the one wave length was reduced.

The preceding paragraph points out the elementary combinations of resonant circuits, which may be used to decrease interference. These circuits may also be used in combination. The principal objection to such circuits as these is the complication of apparatus and of tuning. Another objection is that although these circuits may reduce the strength of the interference greatly, they always * somewhat reduce the desired signals at the same time, due to the additional losses in these circuits. This latter objection is not as serious as it may appear, as the loss in strength of the desired signal may be made up for by the use of the vacuum tube as an amplifier. The complication of tuning also becomes of little weight as a disadvantage in the special case when the receiving set is permanently adjusted for one particular wave length, and it is not necessary to receive any other wave length.

Fig. 915 shows the simple receiving circuit applied to the audion detector for the reception of spark signals. This circuit is suitable for the reception of any radio signal except undamped wave telegraph. To get the maximum

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* This assumes that the receiving circuits were at their best adjustment before adding the extra circuit, and that no regenerative action of an audion detector is introduced by the added circuit.

results from a circuit of this type a *"C"* battery with potentiometer would have to be inserted as in Fig. 811. This serves to regulate the steady value of D. C. voltage applied to the grid, so that the plate current will vary about a point on the characteristic curve of the plate current where the increases in current are much greater than the decreases. Either a potentiometer or a switch to change the number of cells in the plate circuit battery may also be provided for changing the voltage applied to the plate. (The change of plate voltage also affects the point on the plate current characteristic about which the tube works.) It should be recalled at this point that the circuit of Fig. 915 is the one in which the vacuum tube amplifies the radio frequency and *then* detects the signals by the check valve action in the plate circuit.

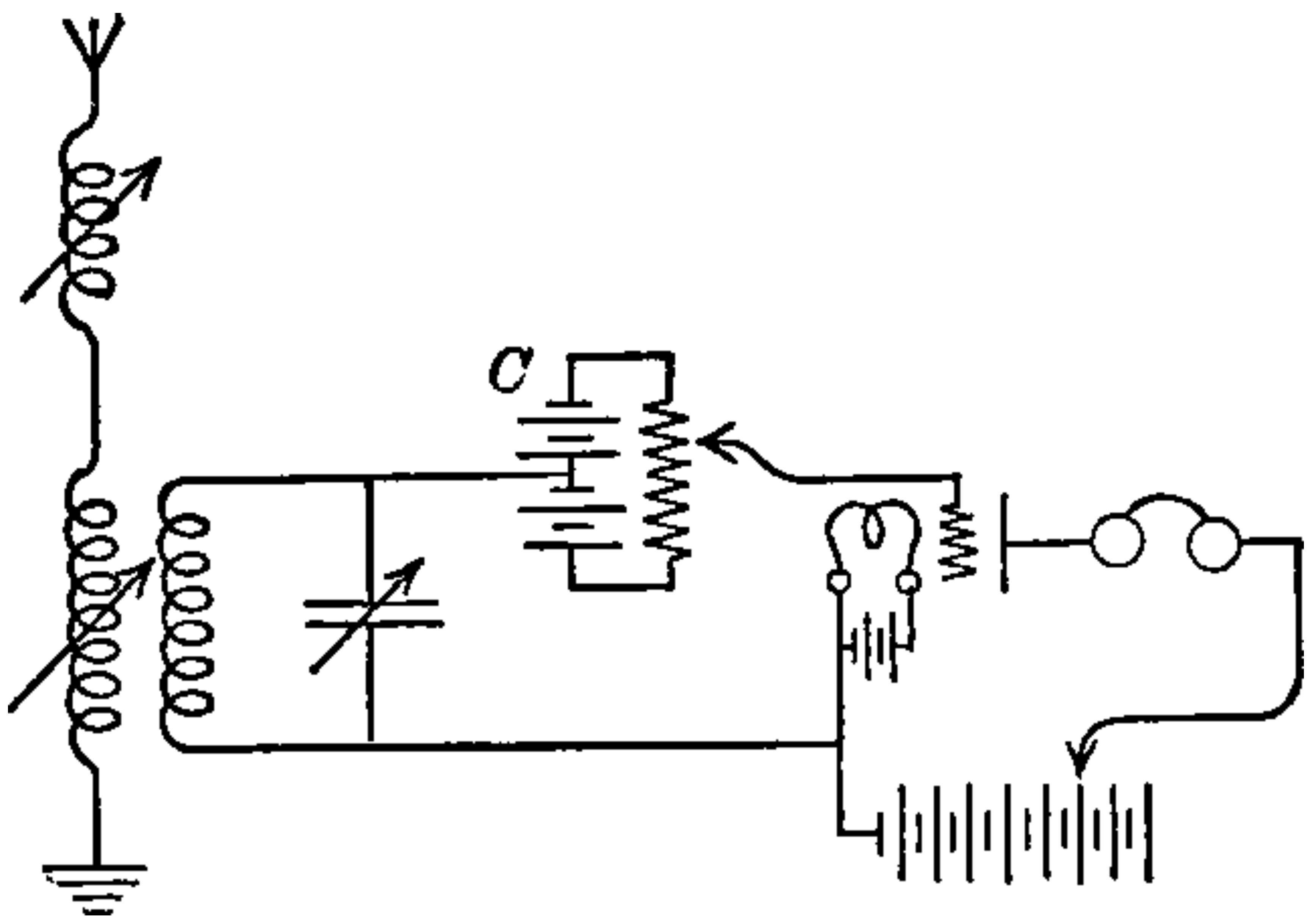

FIG. 915.

Fig. 916 shows the circuit for utilizing the other type of audion detector action (for same field of use as Fig. 915). In this case, as explained in connection with Fig. 809, the detector action takes place in the grid circuit, the audio frequency result being amplified after detec-

dary of the coupler. As the telephones tend to prevent radio frequency variations from occurring in the plate current, a small "bridging condenser," C_3, is usually placed in parallel with the phones to shunt these variations around them. If the tickler coil is connected with the proper polarity, this energy will add to that of the incoming signal and thereby increase the strength of the audible signal. This is known as regenerative amplification. With circuits such as that of Fig. 917 the loudness of the received signals increases with increase of the percentage of the radio frequency energy passed from the plate circuit back to the input of the tube, up to the point where the "feed back" action becomes great enough to cause the tube to generate undamped oscillations. At this point the action of the receiver changes to autodyne receiving, but regenerative amplification is still present. (It should be recalled that in receiving spark signals with a heterodyne or autodyne, the irregularity of the beat action breaks up the audible tone of the received signal.) One result of regenerative amplification is that with spark signals the number of

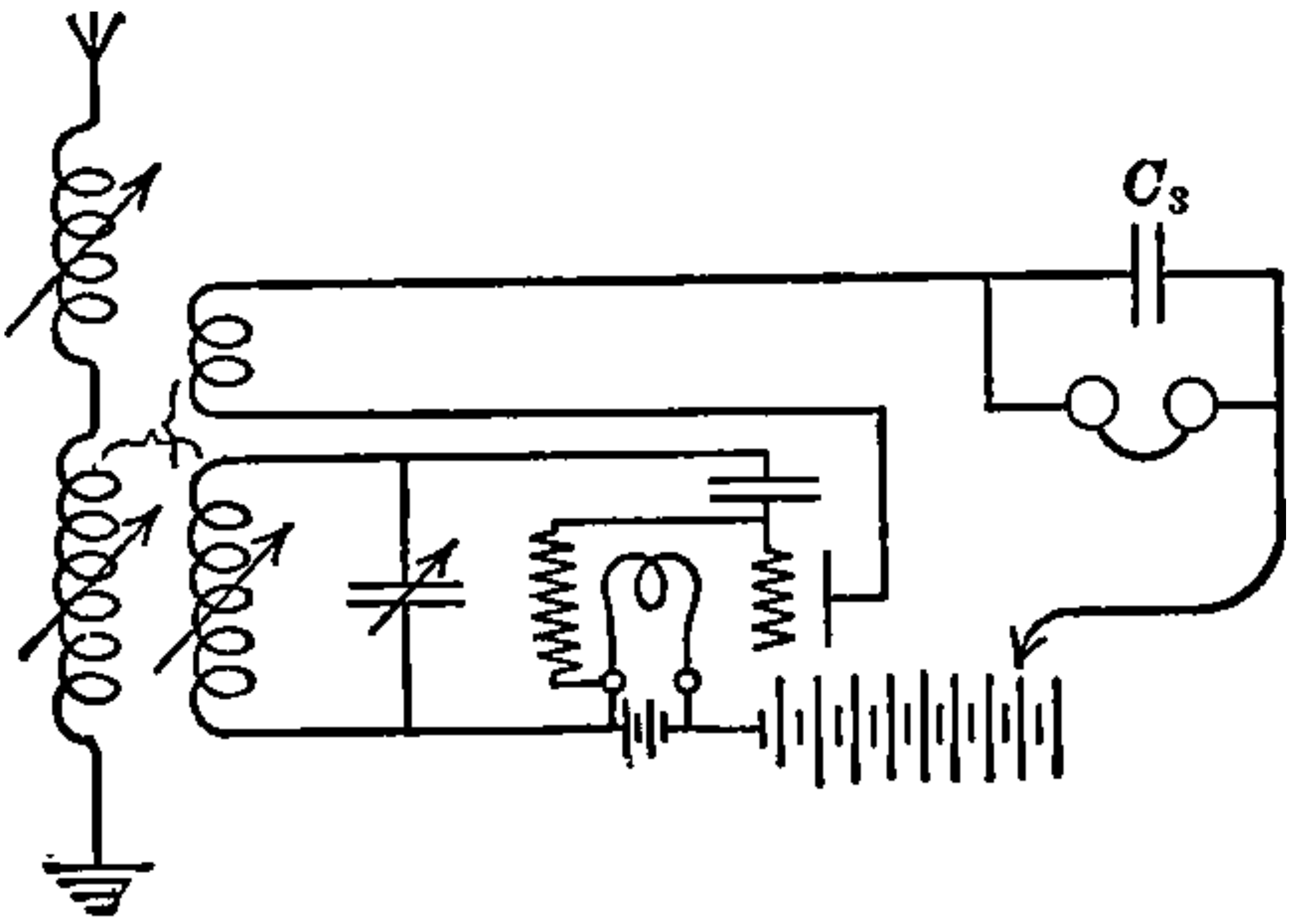

FIG. 917.

oscillations in a wave train (that is, the length of the wave train) is increased much beyond that of the wave train striking the antenna. The reason for this may be seen by considering the case of a clock (with a pendulum) which has stopped on account of running down. If a few gentle pushes are given to start the pendulum swinging, it will continue to swing for a length of time out of all proportion to the pushes given to start it. The reason that the pendulum continues to swing for some time is that the clockwork mechanism is helping to keep the pendulum going, but is not pushing quite hard enough to prevent its finally stopping. This action is very closely akin to that which a regenerative amplifier has on a damped wave train. One of the results of this stretching out of the wave trains is that with high spark frequency, or with long waves, the wave trains are apt to over-lap appreciably. It may be seen that the overlapping of the wave trains tends to cut down the *variation* of radio frequency power passing through the electrical check valve, so that the amplification of *sound* produced will not increase as rapidly as would be expected from the simple regenerative theory. Any vacuum tube generating circuit may have its component parts so arranged that the amount of energy fed from the output back to the input is not quite sufficient to produce continuous oscillations. The circuit is then the basis of a regenerative receiving circuit. Likewise, any regenerative receiving circuit may be made to generate undamped oscillations and act as an autodyne detector, unless the tube is poor, or the losses in the circuit are high.

A simple vacuum tube circuit for the reception of undamped wave telegraph signals is shown in Fig. 918. This circuit makes use of the generating action of the circuit of Fig. 512. The small capacitance condenser in the grid circuit causes the detector action to take place in the grid circuit. The sensitiveness of a circuit, such as this, is affected to a marked extent by the amount of radio frequency fed from the plate circuit back to the grid circuit; that is, by the coupling between these two circuits. This coupling affects not only the generating action of the tube, but also the detector action. Close coupling, although producing a strong heterodyne action, causes the tube to be worked so hard as a generator that it is no longer sensitive as a detector. The best results are usually obtained with coupling not quite loose enough to stop generation of undamped oscillations.

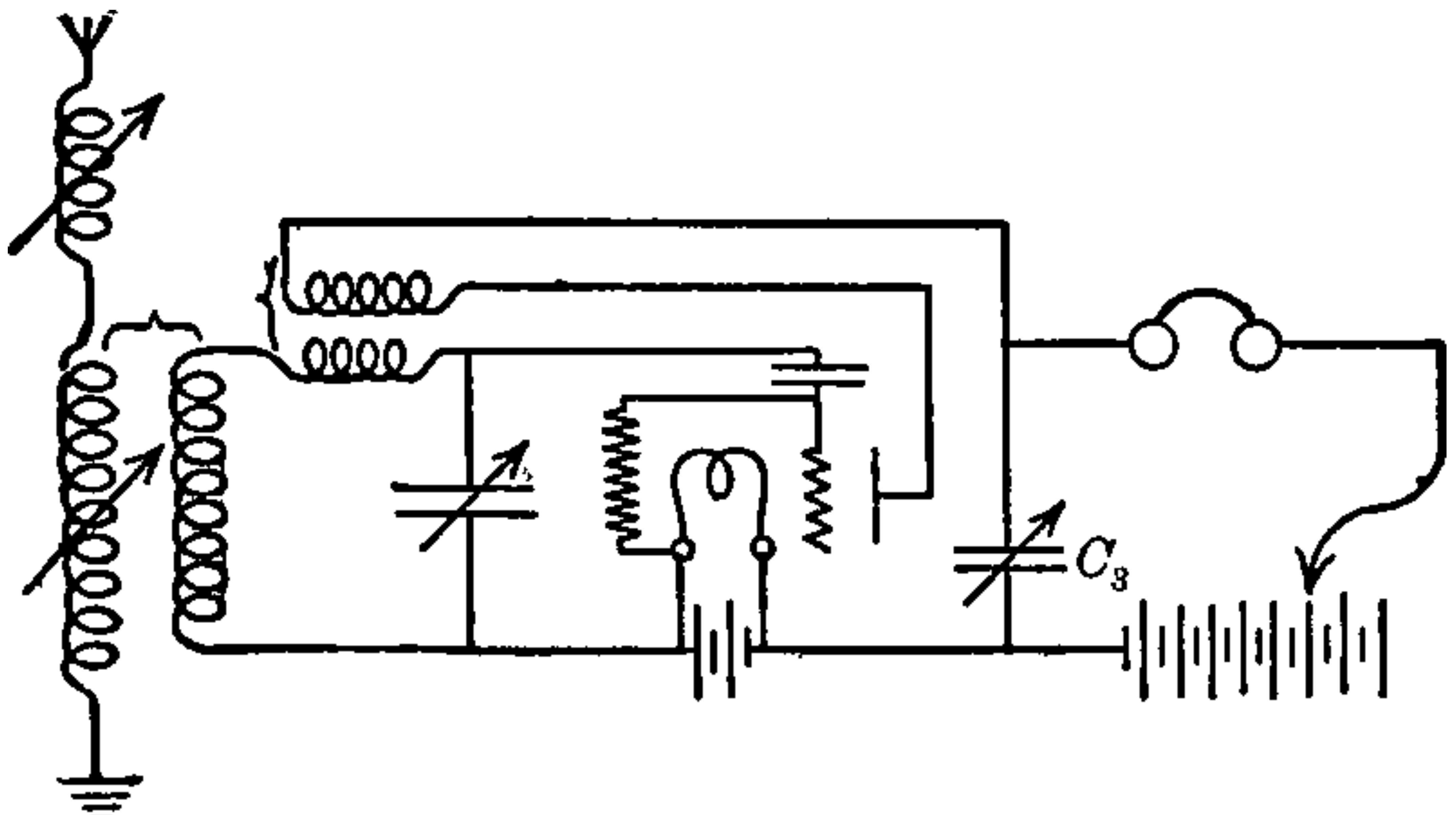

FIG. 918.

If the condenser in the grid circuit of Fig. 918 is omitted the detector action of the tube is changed to that of the circuit of Fig. 811 (see explanation accompanying Fig. 811), while the heterodyne action remains essentially unchanged.

quencies. The second class is designed for the amplification of radio frequencies and gives no amplification of audio frequencies. The third class includes both audio and radio frequencies, giving amplification over an enormous range of frequencies. This third class is the resistance coupled type (in which the impedance in the plate circuit, see Fig. 507, is principally resistance) and gives less amplification per tube than the other types.

The audio frequency amplifier takes the output *from* the detector and amplifies it through one or more tubes before it reaches the phones. The radio frequency amplifier takes the radio frequency from the secondary of the coupler and amplifies it through one or more tubes *before* it reaches the detector. It is evident that both radio frequency and audio frequency amplification may be made use of in the same receiving system. In either of the first two classes of amplifiers there is more or less limited range of frequencies over which the amplifier will give good results. Outside of this range the amplification falls off. In radio communication the range of audio frequencies encountered is approximately from 200 to 2000 cycles per second. One set of apparatus may be designed to cover this range with satisfactory results. The range of frequencies encountered in "radio frequency" is very wide, ranging from 10,000 to 3,000,000 cycles per second. The second class of amplifier, with a particular set of apparatus gives good results over only a small portion of this total range. This limited range is, however, not by any means entirely a disadvantage. Using an audio frequency amplifier any audio frequency disturbance that gets into the amplifier system (such as "other signals," "static," and disturbances from electrical machinery) is amplified at the same time that the desired signal is amplified, and at times appears to be amplified more than the signal is. Using the radio frequency amplifier, only radio frequency disturbances are amplified, and even radio frequencies, if widely different from the frequency for which the apparatus was designed, are not amplified. The result is that when using a high degree of amplification an audio frequency amplifier will produce more undesirable (stray) sound than a radio frequency amplifier. As stray noises tend to drown out the desired signal, this is an advantage in favor of the radio frequency amplifier. The circuits of the radio frequency amplifier, are essentially the same as those of the audio frequency amplifier, but the proportions of the apparatus are very different. This difference is due primarily to the difference in action of inductance and capacitance at the different frequencies. It should be recalled that the difficulty that an alternating current encounters in getting through an inductance varies *directly* with the frequency, while the difficulty that the same current encounters in getting through capacitance varies *inversely* as the frequency. As a numerical example, the secondary of the transformer in an audio frequency amplifier might have as much as 100 henries inductance, while a radio frequency amplifier using the same type of circuit would have a relatively few millihenries inductance in the secondary of its transformer. At radio frequencies the effects of the capacitance of the coils, and other small capacitances in the circuit, are very noticeable, special care being necessary to prevent the inductances being practically short-circuited by the capacitance between the various turns of the inductance coils. The capacitance between the plate and grid inside of the tube (and their connections outside of the tube) couple the plate and grid circuits (see Fig. 515 and accompanying explanation) and tend to feed enough of the output of the tube back to its input to cause the circuit to act as a generator of undamped oscillations. If the amplifying circuit acts as a generator it is no longer usable as an ordinary amplifier. Naturally, the greater the amplification the smaller is the percentage of the output that can stray back to the input without causing this trouble. Due to these effects of capacitance a radio frequency amplifier is not designed for as high amplification *per tube* as the audio frequency amplifier. Contradictory as it may seem, this does not necessarily lead to a weaker signal in the phones when using a fixed number of steps of amplification. The reason for this is that with ordinary (non-regenerative) audion circuits the audibility of the signal, or the amplitude of the audio frequency variations produced in the plate current, varies as the *square* of the radio frequency voltage applied to the grid of the tube to produce this change. This means that, for instance, an amplification of radio frequency voltage of four before application to the detector will produce the same increase in signal strength as an audio frequency amplification of 16 after the signal is detected, or that an amplification of N times by radio frequency amplifiers produces as great an increase in signal as an amplification of N^2 by audio frequency amplifiers. This relation does *not* apply to the autodyne type of detector, for in this case the audibility of the output varies only directly as the first power of the radio frequency input, so that radio frequency or audio frequency amplification is equally effective in producing increases in the strength of the signal.

In this case a strong signal is apt to cause so large an accumulation of electrons on the grid that the plate current will be stopped by this negative charge on the grid, and the tube will temporarily cease to operate.

Fig. 921 differs from Fig. 920 in two respects. First, the transfer of energy from the detector tube to the amplifier tube takes place through a transformer. Second, the receiving set to which the amplifier is attached has a tickler coil which provides a means for feeding part of the radio frequency output of the detector tube back into the input of the same tube. This feed back may be utilized to produce regenerative amplification of spark signals (independent of the amplification produced by the amplifier tube), or to cause the detector tube to generate undamped oscillations and act as an autodyne detector. The bridging condenser provides a path for the radio frequency around the primary of the transformer. This is necessary as the impedance of the transformer winding for radio frequency, due almost exclusively to the distributed capacitance of the

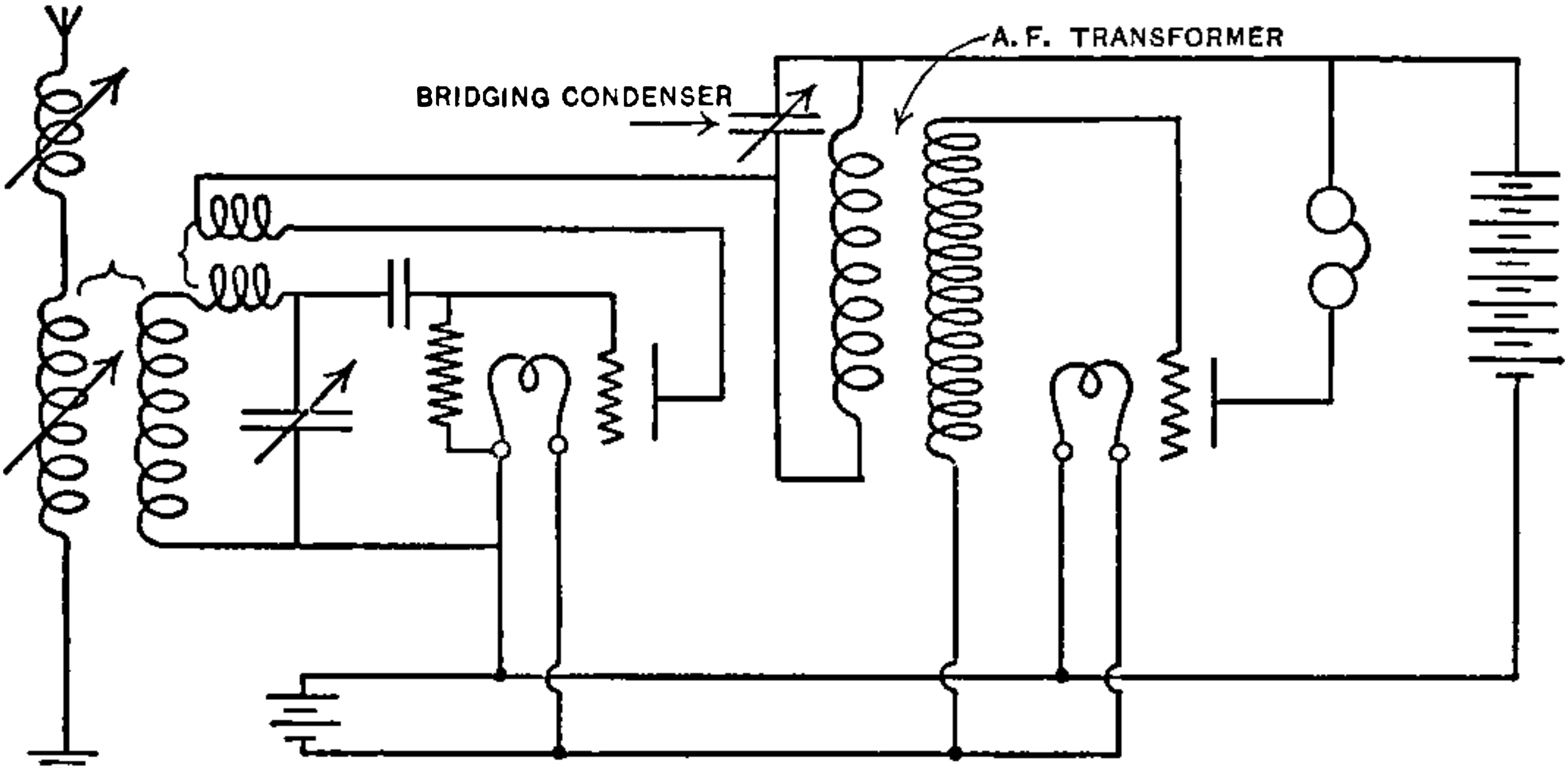

FIG. 921.

winding in parallel with the inductance of the winding, is apt to be too high to permit proper operation of the tickler coil. In this circuit the audio frequency variations, which occur in the plate current, pass through the primary of the transformer and produce similar changes in voltage across the secondary of the transformer. These changes of voltage are in turn applied to the grid of the amplifier tube and produce greater changes in the plate current of the amplifier tube.

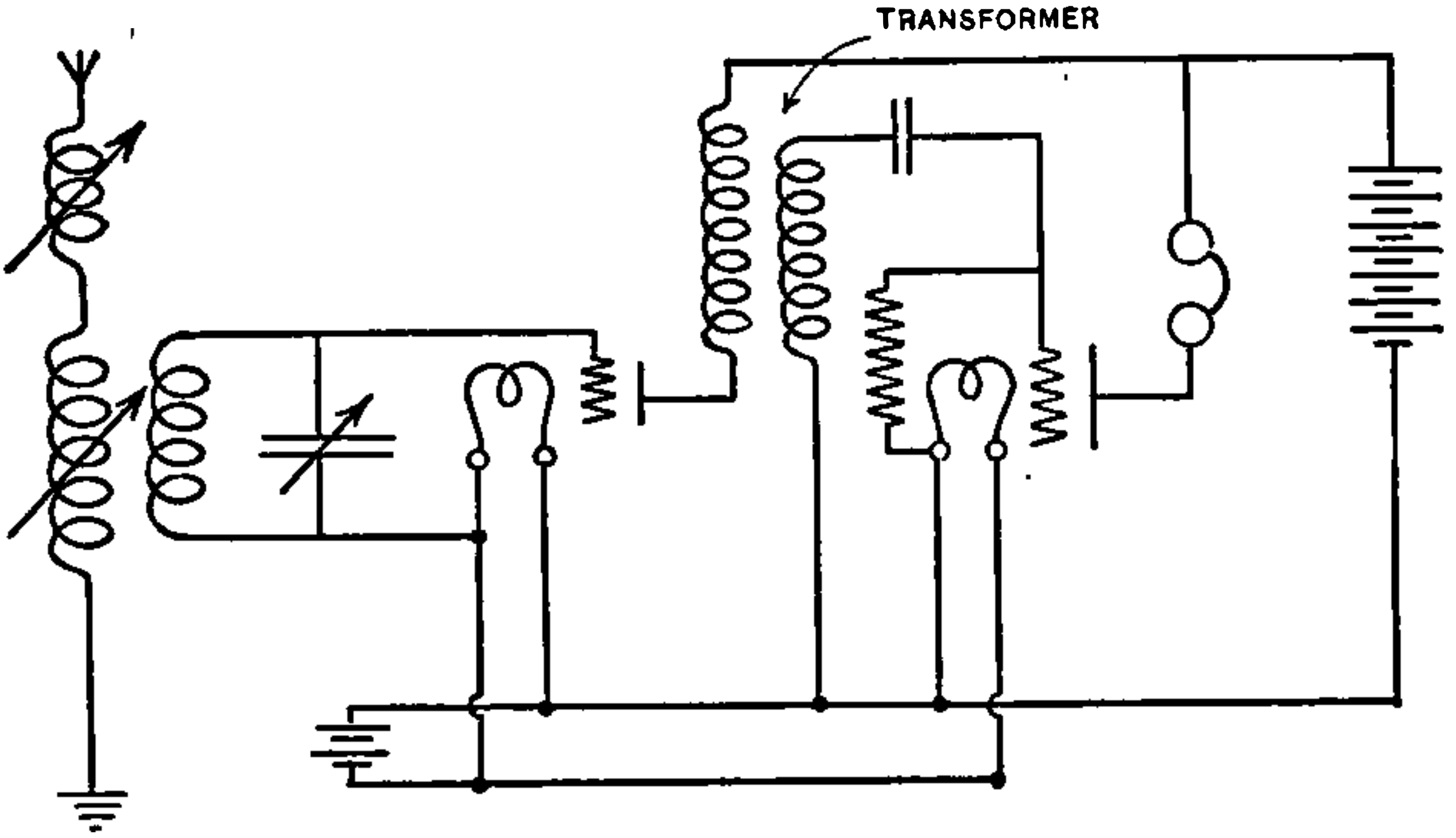

FIG. 922.

Fig. 922 shows a one-step radio frequency amplifier (in which the radio frequency is amplified before reaching the detector). This circuit is essentially the same as that of Fig. 505.

Fig. 923 shows a detector and three-step amplifier connected to a spark receiving set. This circuit is of the type that uses transformers to couple the various tubes. The resistance units, marked *R,* in the filament circuits of the amplifier tubes are of such value as to produce a small voltage drop (say one volt) between the filament and the connection to the grid circuit when the normal filament current is flowing. This value of resistance is picked out to give a drop of voltage which will hold the average value of the grid voltage at a desirable point for the efficient operation of the amplifier. As shown, it will hold the average value of the grid voltage at a small negative value (with respect to the filament). The rheostats in the filament circuits are not peculiar to any type of amplifier, and are frequently used as shown (simply to regulate the filament currents to the desired value).

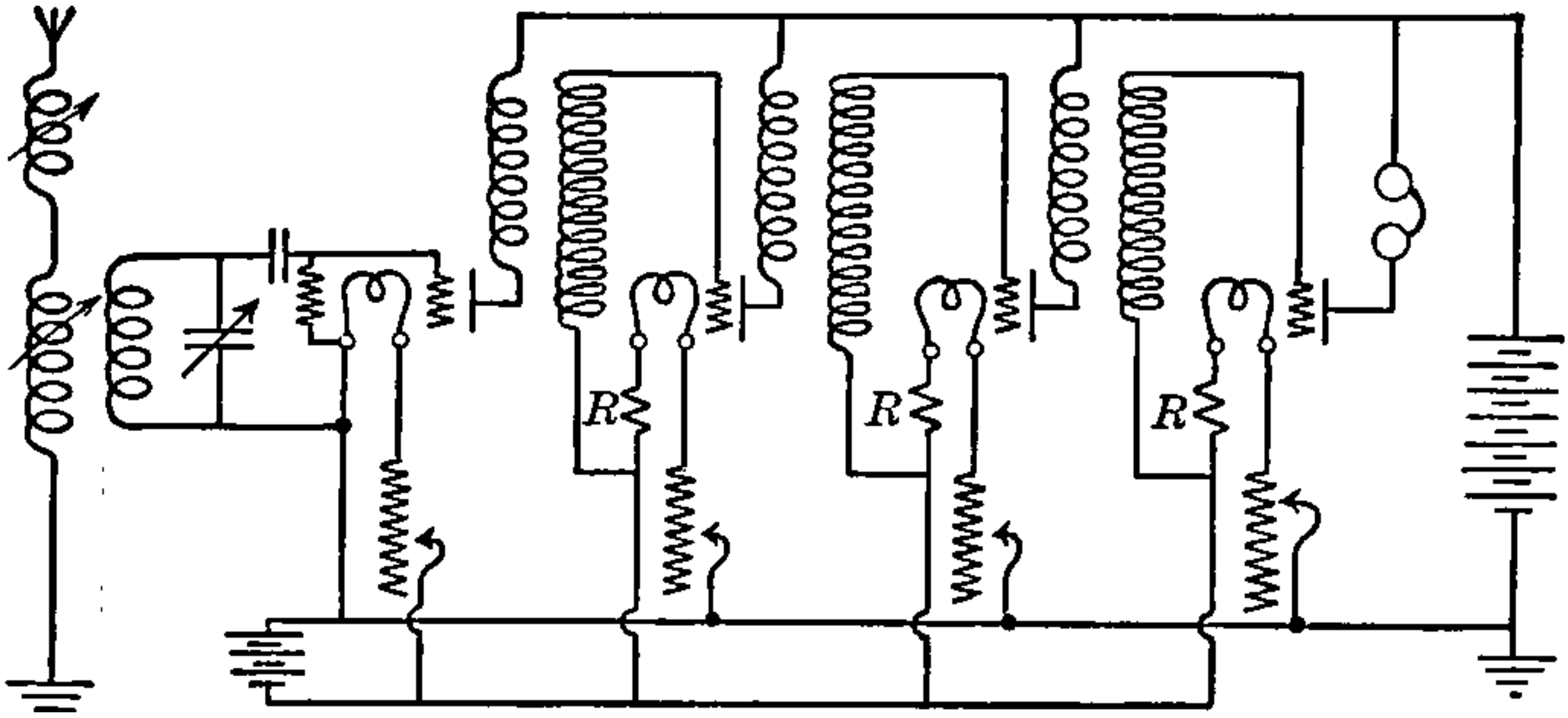

FIG. 923.

In the majority of the preceding cases it has been assumed that where a high voltage D. C. was required it would be taken from a battery. The objection to using a supply directly from a D. C. generator is that, although such a supply is substantially constant as measured by ordinary means, it is sufficiently irregular to produce much undesirable noise in a system which uses it. The prime source of this irregularity is the commutator of the gener-

bility of reducing the irregularities in the supply current, and points out that the *L* and *C* must be large enough so that they are resonant to a frequency much lower than the frequencies it is necessary to reduce. Another unit exactly like the first one might be added to the output of the first, and would produce a further reduction of disturbance.* Other filter circuits can be made to separate various A. C. frequencies from each other.

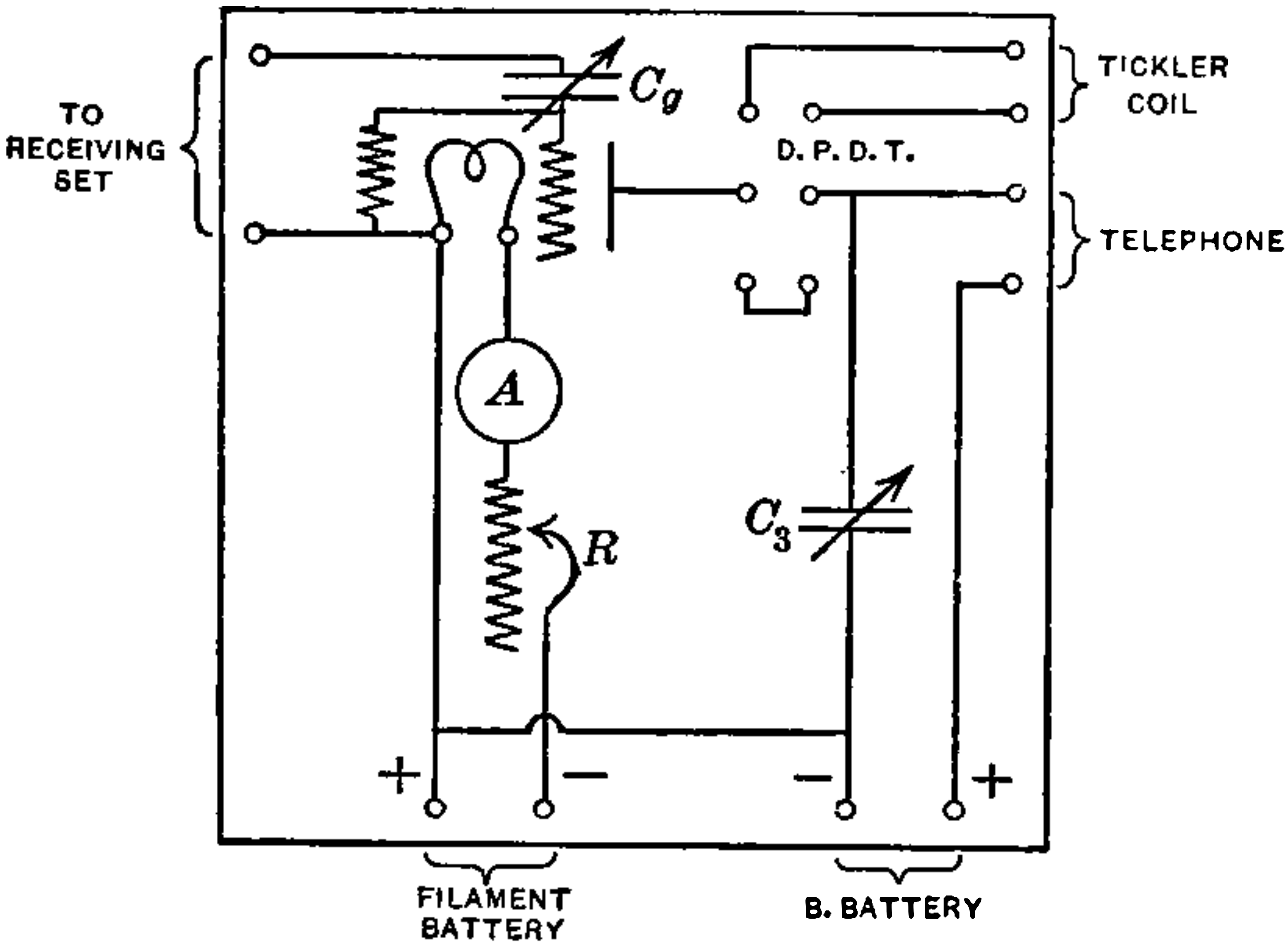

FIG. 925.

When using an audion detector it is frequently convenient to have the various pieces of apparatus needed for the control of the audion circuits assembled as a single unit. Such a device is called an "Audion Control Box." Fig. 925 shows the connections of a simple audion control box. It will be seen that this box contains a filament ammeter *A*,

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* The reduction for additional steps proceeds with an approximately geometric ratio rather than an arithmetical ratio.

and filament rheostat *R*, a bridging condenser C_3, a grid condenser C_g, a grid leak, and a switch which permits a tickler coil to be inserted in the plate circuit, or to be entirely disconnected from the plate circuit. A filter and potentiometer to adapt the audion to operation from an ordinary D. C. lighting circuit are also provided in some cases. All necessary terminals are brought out to binding posts.

"Static" and its elimination, or the reduction of its bad effects, will be discussed at the end of Chapter XI.

CHAPTER X.

RADIO TELEPHONE.

Sound is produced in the telephone receiver by movements of the receiver diaphragm. If the sound produced is to be a reproduction of speech, the diaphragm must vibrate in the same manner in which it would vibrate if acted upon directly by the sound waves of the original speech. As the movements of the diaphragm when receiving signals are controlled directly by the electromagnetic action of the current flowing through the windings of the receiver, evidently, this current must *vary* in the same manner that the original sound wave in the air varied. It should be remembered that all receivers have strong permanent magnets in them which produce a pull on the telephone diaphragm much greater than the greatest pull which will be exerted, due to the currents passing through the windings of the receiver. As a result of this, a current which opposes the magnetization due to the permanent magnet causes a slight decrease in the pull on the diaphragm, and a current in such a direction that it aids the permanent magnet slightly increases the pull. Any steady current makes a small constant change in the pull on the diaphragm but has no effect on vibrations of the diaphragm, so that a steady current may be superimposed on the variations of current without affecting the action of the receiver.

In the simplest telephone system (where a metallic circuit is used to connect the transmitting device with the receiver) a variable resistance is connected in series with

is always in one direction. It may be thought of as consisting of the constant current *OA* with the variations superimposed on it. If desired, the current *OA* may be eliminated from the telephone circuit by passing the current from the microphone through the primary of a transformer, as in Fig. 1003. The current through the *primary* of the transformer may then be represented by Fig. 1002. The current in the secondary of the transformer and the phones will be as shown in Fig. 1004.

The fundamental requirement for radio telephony was the discovery of some type of radio frequency oscillation, which when received by a radio receiving set could produce audio frequency variations of current such as those shown in Fig. 1002 or 1004. As ordinary detectors have some element which gives a check valve action, and therefore an approximately unidirectional current in the output, it seems to be out of the question to draw a current, such as that of Fig. 1004, directly from the detector regardless of the nature of the radio frequency supplied to the detector. The current of Fig. 1002 is purely unidirectional, however, and thus it appears that it might be produced by a detector. If it is to be produced by a detector it immediately becomes evident that the radio frequency supplied to the detector cannot be intermittent, for the current shown never stops altogether. The only sort of radio frequency oscillation

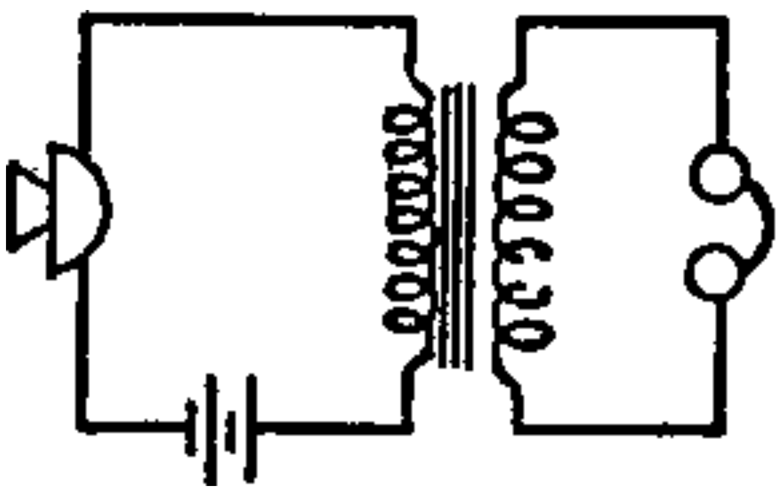

FIG. 1003.

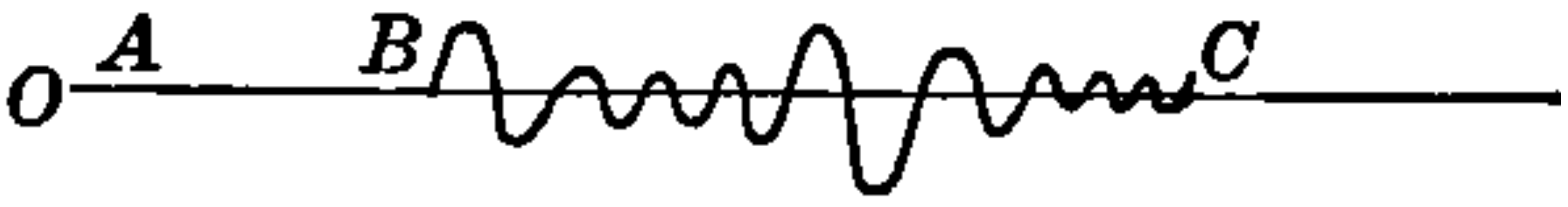

FIG. 1004.

which has been considered so far, which is not intermittent, is an undamped oscillation. As was pointed out in a preceding chapter, an undamped oscillation (of constant amplitude) when applied to an ordinary detector produces a series of pulses of current all in the same direction, and, due to the short time between pulses and the capacitance of the circuit, current passing through a telephone attached to the detector is practically constant, as long as the undamped oscillation does not change. If the amplitude of the undamped wave is increased the current produced by the detector increases proportionately. In any case the telephone current changes in amplitude *only when the undamped oscillation changes.* As a result of this sounds are produced in the phones only when the undamped oscillation changes. (See Figs. 803, 804, 805, and accompanying explanation.)

FIG. 1005.

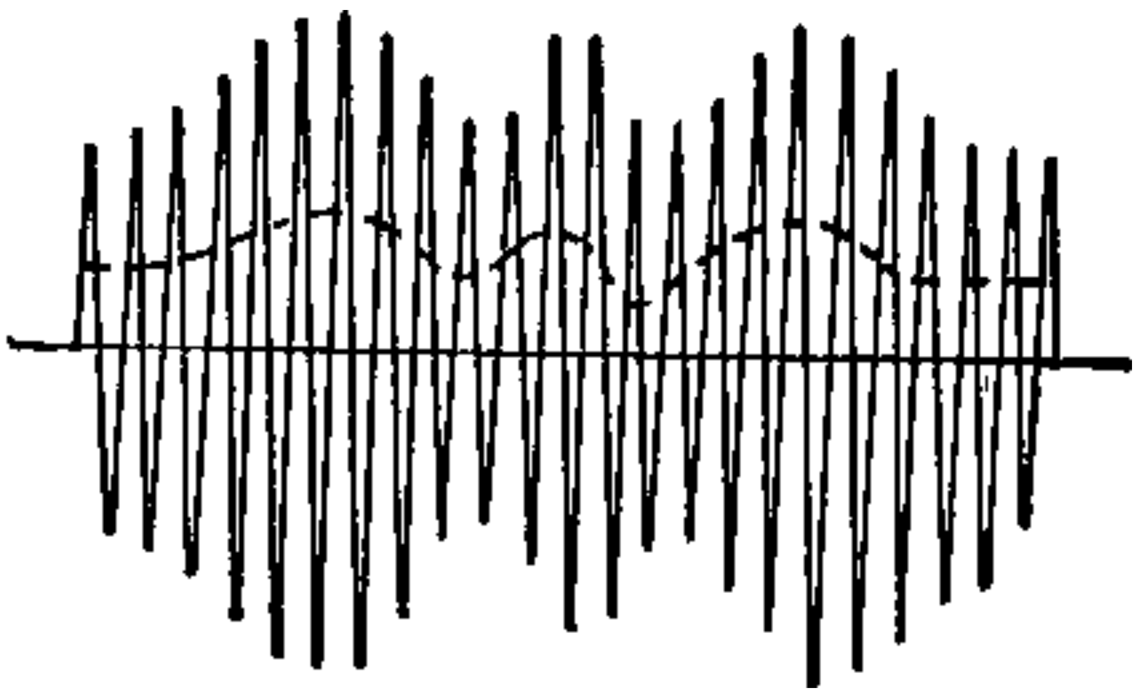

FIG. 1006.

As a change in the amplitude of the undamped wave applied to the detector produces a corresponding change in the current through the telephone at the receiving station, it appears that an undamped oscillation might have its amplitude varied so that the receiving detector would produce an audio frequency current, such as that shown in Fig. 1002. *The process of varying the oscillation to produce this result is known as modulation.* Fig. 1005 shows the necessary variation of current through the phones to produce part of a certain sound. The corresponding radio frequency oscillation which must be applied to a detector to get this current is shown in Fig. 1006.* (The dotted line is a repetition of Fig. 1005.)

Modulation of an undamped wave may be produced by the variation of a resistance, an inductance, or a capacitance in some part of the transmitting system. Only the first two are used practically. The last has been used experimentally. In all practical cases the microphone is used as a variable resistance to be acted upon by the sound waves. The microphone may then act directly as a modulator, or it may control another variable (either inductance or resistance), which in turn acts as a modulator.

Two devices which may readily be used as variable resistances in connection with a modulator circuit have been explained. These are the three-element vacuum tube and the microphone. The three-element vacuum tube is not directly controllable by sound waves, but may easily be controlled by a varying voltage derived from a microphone circuit.

The variable inductance suitable for use as a modulator is a device developed by Mr. E. F. W. Alexanderson and the General Electric Co. It consists of an iron cored inductance coil in which the variation of the inductance is produced by varying the degree of magnetic saturation (and

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* Another type of undamped oscillation in which the principal change takes place in the *frequency* is a possibility for use in radio telephony. No system in practical use depends entirely upon this variation of frequency for modulation, but slight changes in frequency undoubtedly occur in many circuits, which are intended to operate entirely by change of amplitude.

set up through the winding by a given amount of current. To readily understand the change of inductance which takes place in the magnetic amplifier, it is desirable to consider the inductance as being measured by the number of turns in the winding multiplied by the change in flux produced by unit change in current. The *change in flux* produced by unit change of current is then the only variable. Consider the curve in Fig. 1008. This is a typical shape for a saturation curve for iron. From this curve it should be evident that a small change in the total ampere-turns magnetizing the iron has widely different effects, as to the change of flux it produces, depending upon the total ampere-turns acting upon the circuit before the change. The larger the total ampere-turns acting to magnetize the iron the smaller will be the *change* of flux produced by a small change in the current through the winding. This shows that relatively large values of current flowing through the control circuit of the magnetic amplifier cause the inductance of the variable inductance circuit to approach its lowest value. On the other hand, small control currents give rise to relatively high inductance in the variable inductance circuit.

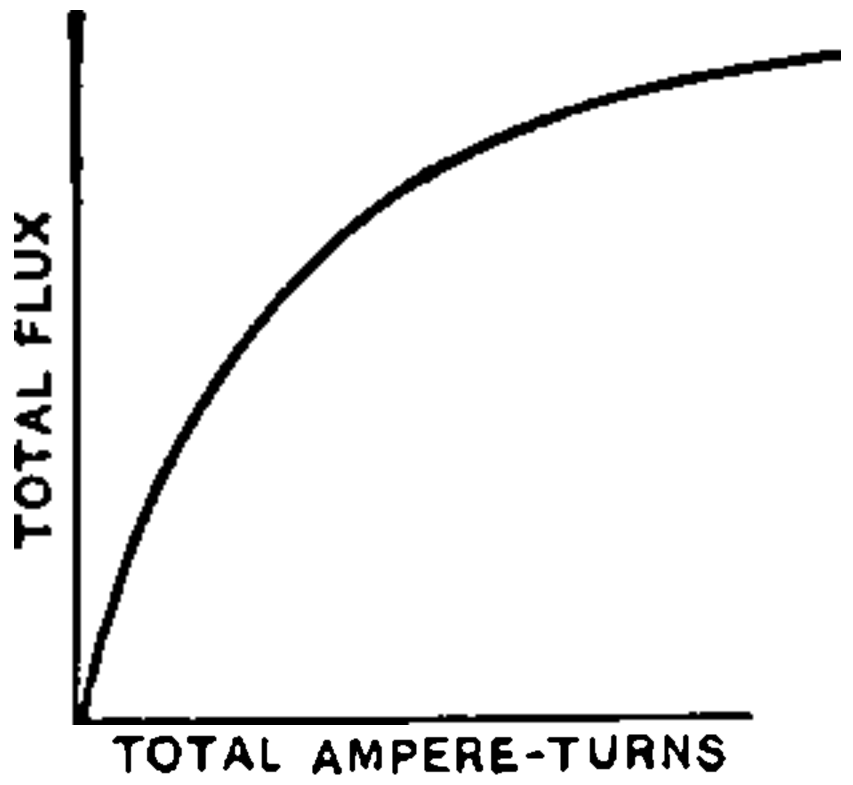

FIG. 1008.

In its usual form the magnetic amplifier has a core consisting of extremely thin iron laminations. In the case of radio frequencies there are two reasons for making laminations very thin. One is to keep the eddy currents in the iron small; the other is to decrease what may be called magnetic skin effect. It is fairly well known that a large portion of a radio frequency current flowing in a solid conductor travels near the surface of the conductor. A similar condition is found with the flux in an iron lamination subjected to radio frequency magnetizing forces. The eddy currents, which are produced in the iron, flow in a direction which tends to prevent the setting up of the flux in the lamination. At the very surface of the lamination the eddy currents in the lamination have no effect, for none of the eddy current surrounds the iron at the surface of the lamination. As soon as a section of the lamination a finite distance below the surface is considered, it is found that it is surrounded by a certain amount of eddy current which decreases the net magnetomotive force acting to produce flux in this particular section of the lamination. The farther away from the surface the section is, the greater is the amount of eddy current surrounding it and, therefore, the smaller the net magnetomotive force left to produce the flux in that section. The result is that there is a very decided magnetic skin effect, which, at ordinary radio frequencies, makes itself felt in even the thinnest laminations that it is practicable to use.

Two broad divisions may be recognized in the manner of applying a modulator to a radio telephone system. In the first division are those types of modulator circuits in which the modulation takes place by direct action upon the radio frequency oscillations. In the second division are those types of circuits in which the modulation takes place by action upon the power supply to the transmitting system (before the power is converted to radio frequency). In each of these cases two further divisions may usually be recognized. First, the modulator in series with the part of the circuit upon which it is acting; second, the modulator in parallel with the part of the circuit upon which it is acting.

Modulators which operate upon the power supply have probably been tried experimentally with every type of undamped wave generator. To be suitable for operation with a modulator of this type, a radio frequency generator must be capable of varying its output at the ordinary audio frequencies. The difficulty of satisfying this requirement (with the control entirely in the power supply) has limited the practical application of this system of modulation to vacuum tube generating circuits. The only limit to the speed with which a vacuum tube generating circuit can change its output is imposed by the tendency of the radio frequency oscillating circuit to continue in a given state. (This condition appears in all systems, but is not really a limitation except with very long wave lengths and low decrement circuits. For example, *modulation* of short wave lengths at low *radio* frequencies is considered practicable.)

As the resistance of the ordinary microphone is much lower than the resistance of the plate circuit of a three-element vacuum tube, a microphone placed directly in series with the power supply to the plate circuit will have but very little effect upon the flow of current (and the power supply) to the tube. Experimentally another three-element vacuum tube has been used in series with the plate circuit of the generating tube, but this combination requires about double the voltage required by one tube and puts a high voltage between the filaments of the two tubes.

If the modulator is capable of absorbing * the necessary amount of power (about the same as the average amount supplied to the plate of the vacuum tube generator) the

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* Only a variable resistance type of modulator is used for control of D. C. power supply.

and thus producing the desired modulation of the radio frequency. The condenser *C* does not form part of the oscillating circuit. Its function is to provide a path for the radio frequency around the inductance of the transformer secondary. The capacitance of *C* is of such value that it offers relatively little impedance to the radio frequency, but at the same time offers high impedance to audio frequencies, so as not to short-circuit the transformer. This elementary circuit, with one modification to apply it to an antenna circuit, is repeated in Fig. 1009B. It should be evident that in a circuit of this type a three-element vacuum tube may be put in the primary circuit of the transformer, in place of the microphone. The resistance of the second vacuum tube would then be controlled by means of a microphone circuit.

The placing of a modulator in parallel with the power supply to a generating circuit will be illustrated as applied to a generating circuit of the type shown in Fig. 1010A. It will be seen that the capacitance of the oscillating circuit of Fig. 1010A consists of two condensers in series, these in turn being placed in series with inductance to form the oscillating circuit. The transfer of energy from the plate circuit to the oscillating circuit takes place according to the method (3b) (see Fig. 510 and accompanying explanation). Transfer of energy to the grid is by direct connection across *part* of the capacitance of the oscillating circuit.* This is a slight modification of the method (4a) (see Fig. 511A and accompanying explanation). This generating circuit with the necessary additions to produce

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* It is easily shown by means of a vector diagram that the phase relation of the voltage applied to the grid by this circuit is satisfactory for operation of the circuit as a generator.

modulation, and the capacitance of the antenna to ground substituted for condenser *C*, is shown in Fig. 1010B. As a modulator placed in parallel with the power supply is effective only when the total power supplied is at least approximately constant, a choke coil of relatively large inductance has been connected in series with the battery. This inductance is large enough so that it prevents the current through the battery from changing appreciably at audio frequencies. Immediately after passing through this choke

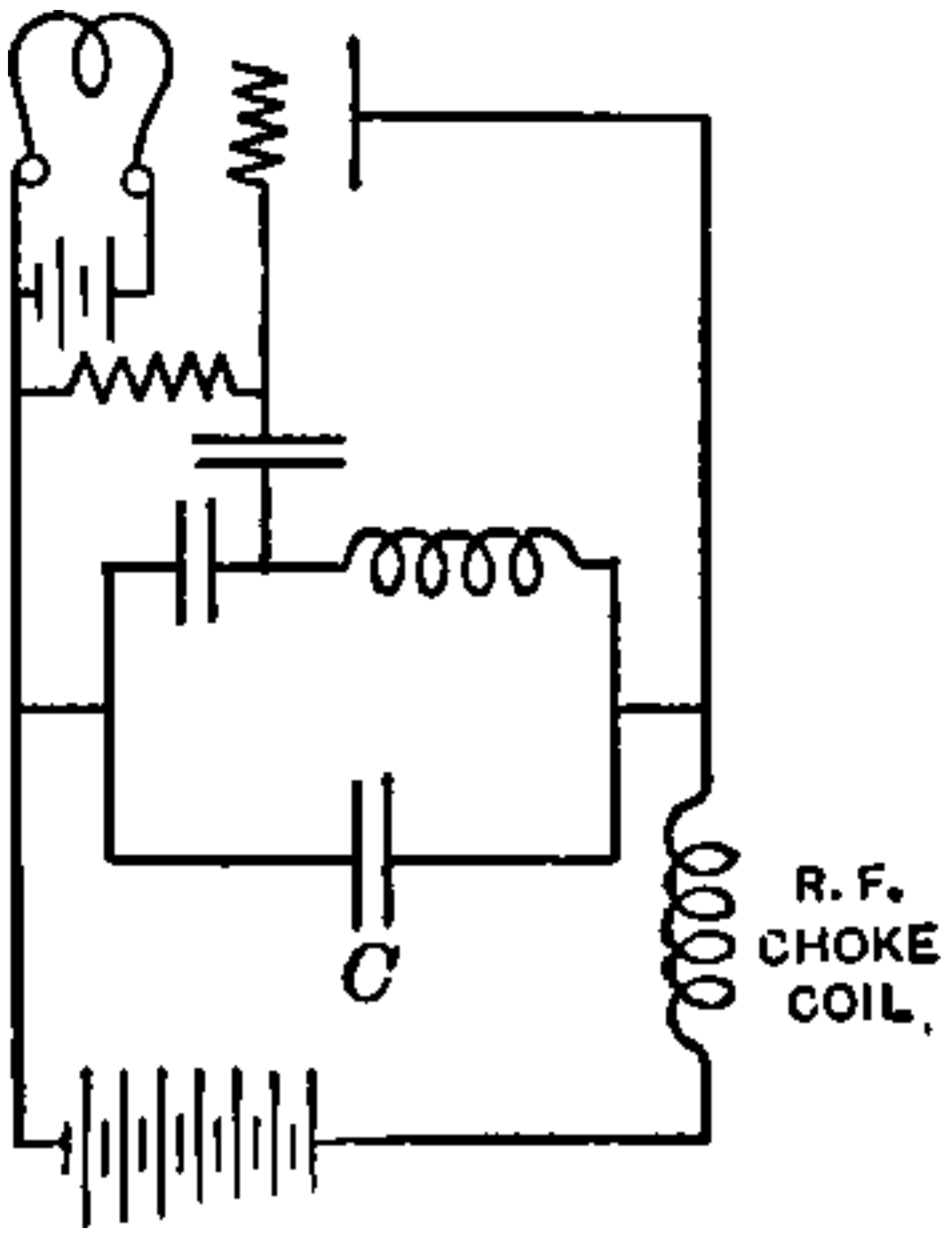

FIG. 1010A.

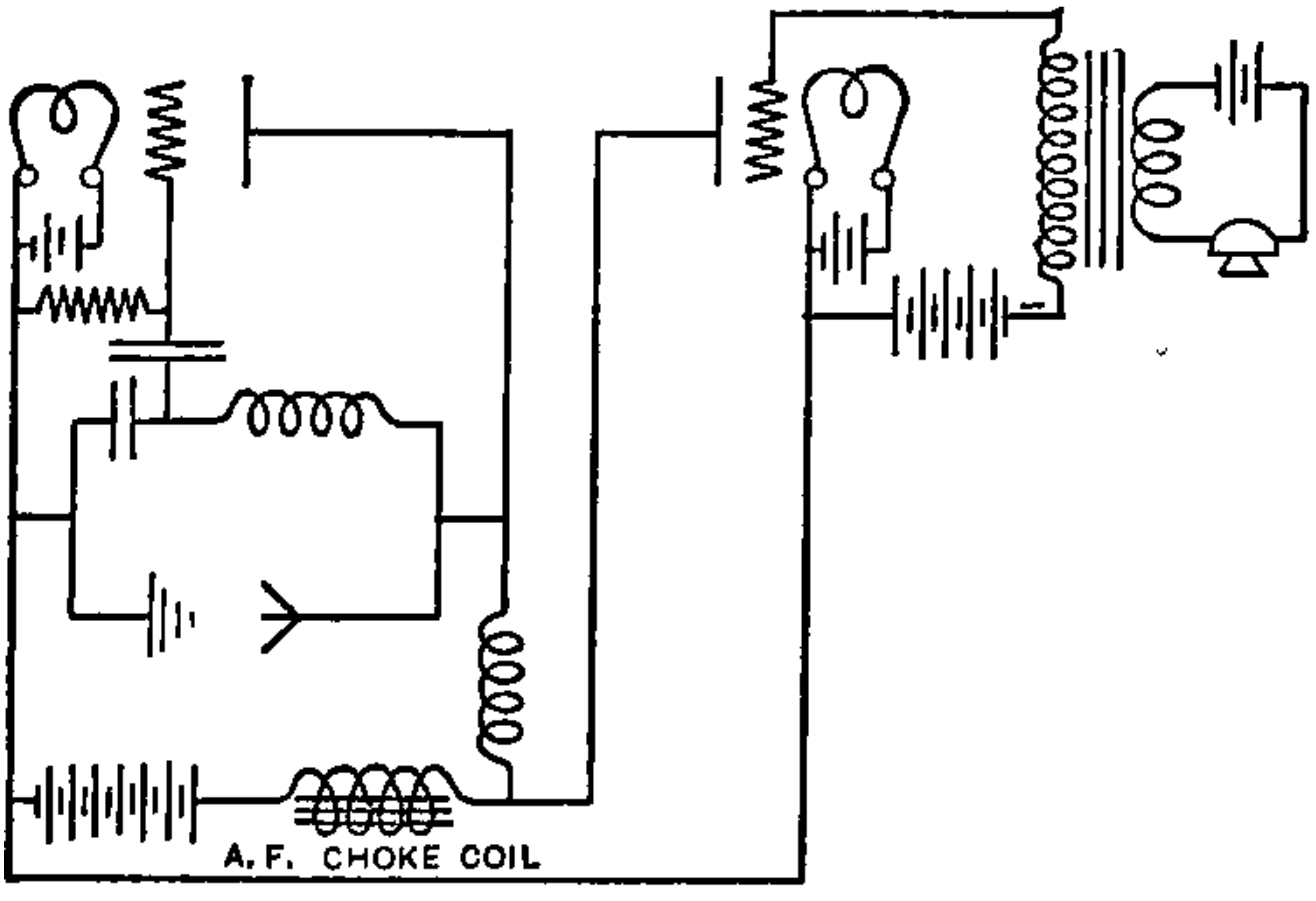

FIG. 1010B.

coil the current splits into two parts. One goes to the plate of the generating tube, the other goes to the plate of the modulator. The amount of current going to the modulator tube is controlled by the resistance of the modulator tube, and this resistance is in turn controlled by the microphone circuit shown. Another tube like the generator tube is approximately suitable for use as a modulator, but slightly better results may be obtained with a modulator having lower resistance. The action of the complete circuit is as follows: When a sound wave strikes the microphone diaphragm the resistance of the microphone changes. The current flowing through the microphone changes correspondingly. This changing current flowing through the primary of the transformer changes the flux through the core of the transformer. The changes of the flux cutting the secondary winding of the transformer produce a voltage in the secondary similar to the sound wave. The variable voltage applied to the grid of the modulator tube causes its resistance to change, and the modulator tube takes correspondingly larger or smaller currents through its plate circuit. The greater the current taken by the modulator tube, the smaller the current left over to go to the generator tube (on account of the approximately constant current supplied). The result of this variation of the current input to the generating tube is that the radio frequency current output of the tube varies correspondingly, thus producing the desired modulation. The battery placed in series with the grid circuit of the tube serves to keep the grid voltage of the modulator tube *negative,* in spite of the variations of voltage applied to the grid circuit by the transformer. It is undesirable to have the grid voltage become positive, for as soon as the grid voltage becomes positive current flows

radio frequency oscillations. Circuits such as this are used to some extent with low power, but it seems impracticable to build single microphones (or even groups of microphones for series or parallel operation) which will control any considerable amount of power. The resistance of a vacuum tube is not suitable for direct connection in series with an antenna, but an equivalent connection might be made by using a transformer (if some means is provided for taking care of the unidirectional conductivity of vacuum tubes).

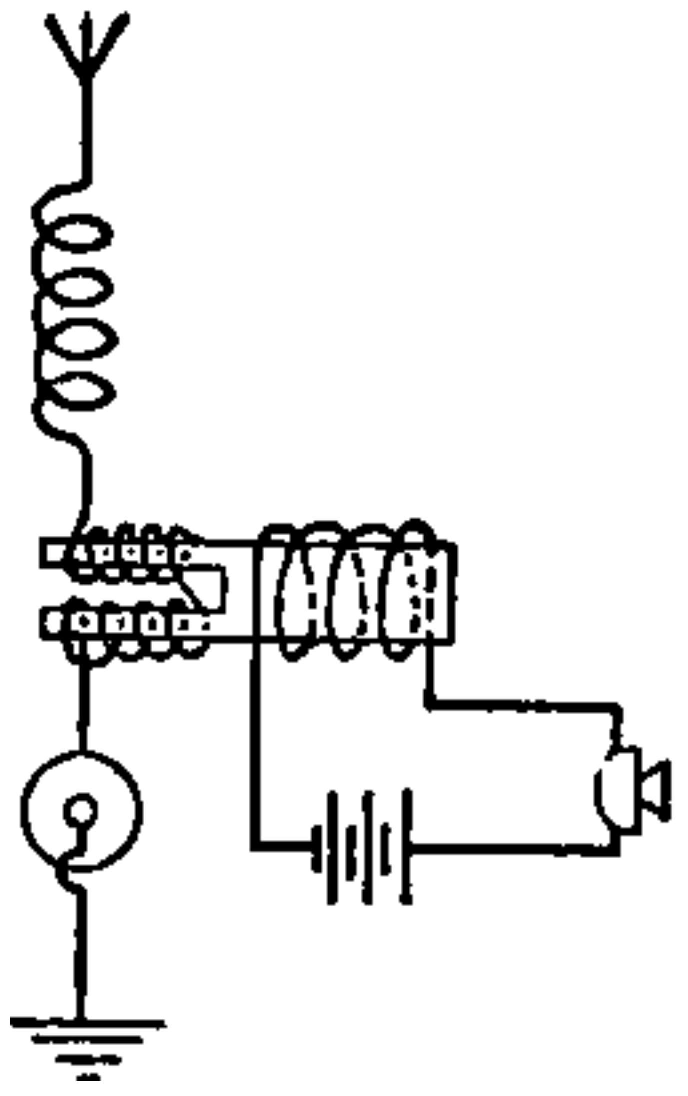

FIG. 1011.

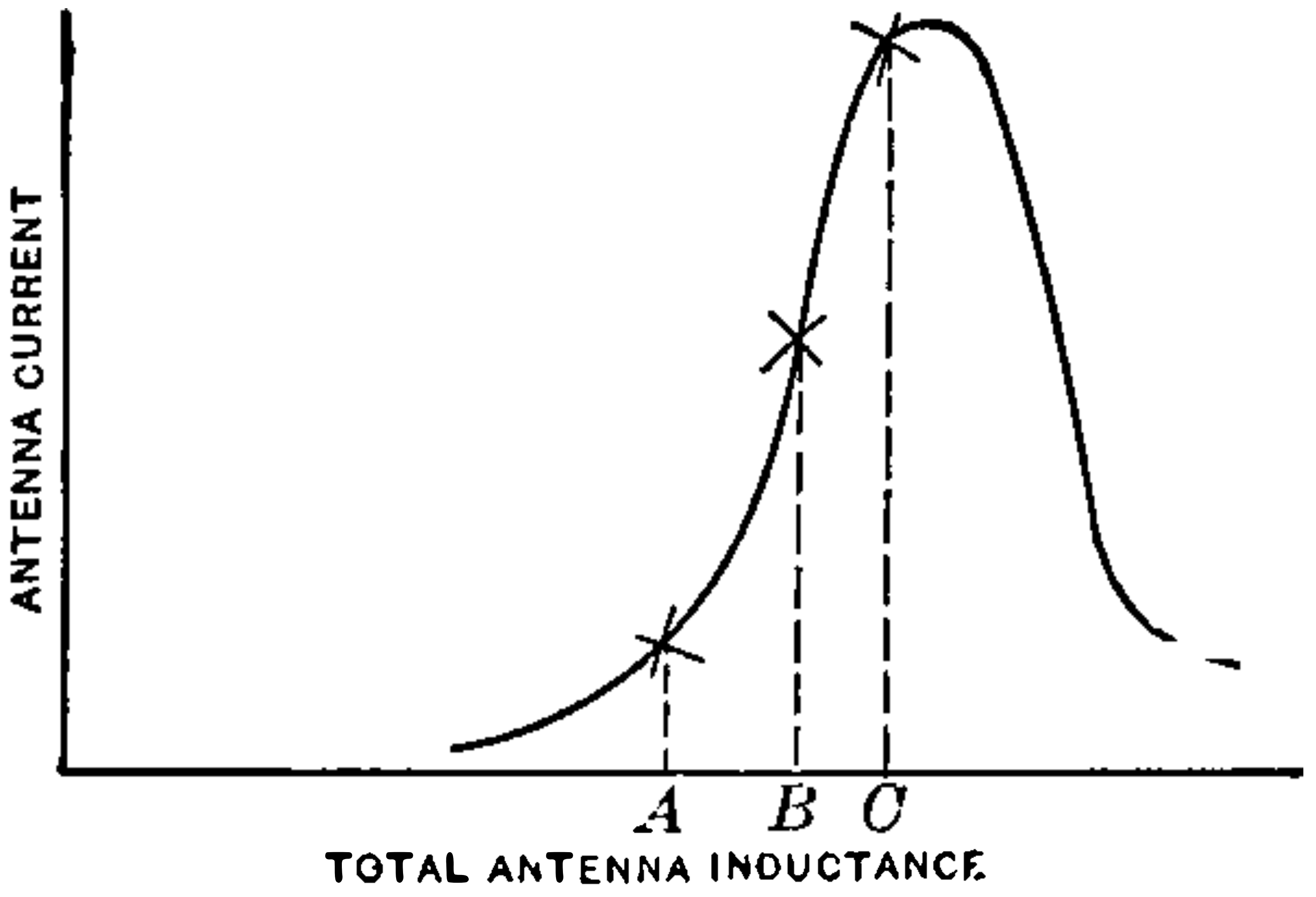

FIG. 1012.

The operation of a modulator which utilizes the change of current near the condition of resonance may well be illustrated by a circuit having a radio frequency alternator and a magnetic amplifier directly in series with the antenna, as shown in Fig. 1011. As the generator delivers a constant frequency (unaffected by changes in the antenna circuit) the current in the antenna will be greatly affected by small changes of inductance in the antenna circuit if the antenna circuit is near resonance. The nature of this change of current is shown in Fig. 1012. A magnetic amplifier whose maximum *change* of inductance is equal to *CA* would be suitable for use with this circuit. To operate as shown, the loading coil in the antenna circuit would be so adjusted that the antenna current would be in the neighborhood of half of its maximum value when the magnetic amplifier has its normal (no speech) inductance. Evidently changes in the inductance of the variable inductance circuit of the magnetic amplifier will be accompanied by changes in the antenna current approximately proportional to the *change* in inductance.

The preceding paragraph dealt with resonance in a series circuit. Parallel resonance is also made use of in modulator circuits. A typical elementary circuit which makes use of a variable inductance modulator in a parallel resonance circuit is shown in Fig. 1013. In this figure the series circuit consisting of the antenna, loading coil, and capacitance of the antenna to ground is tuned to the frequency produced by the generator. The current which will flow in the antenna circuit is then simply *E/R,* where *E* is the *terminal* voltage of the alternator and *R* the effective resistance of the antenna circuit. In this circuit *R* is constant, so that the variations in the antenna current can be produced only by changing *E*. *E* is changed by changing the load on the generator. So far as the effects of load current on terminal voltage are concerned the radio frequency alternator acts in much the same manner as a

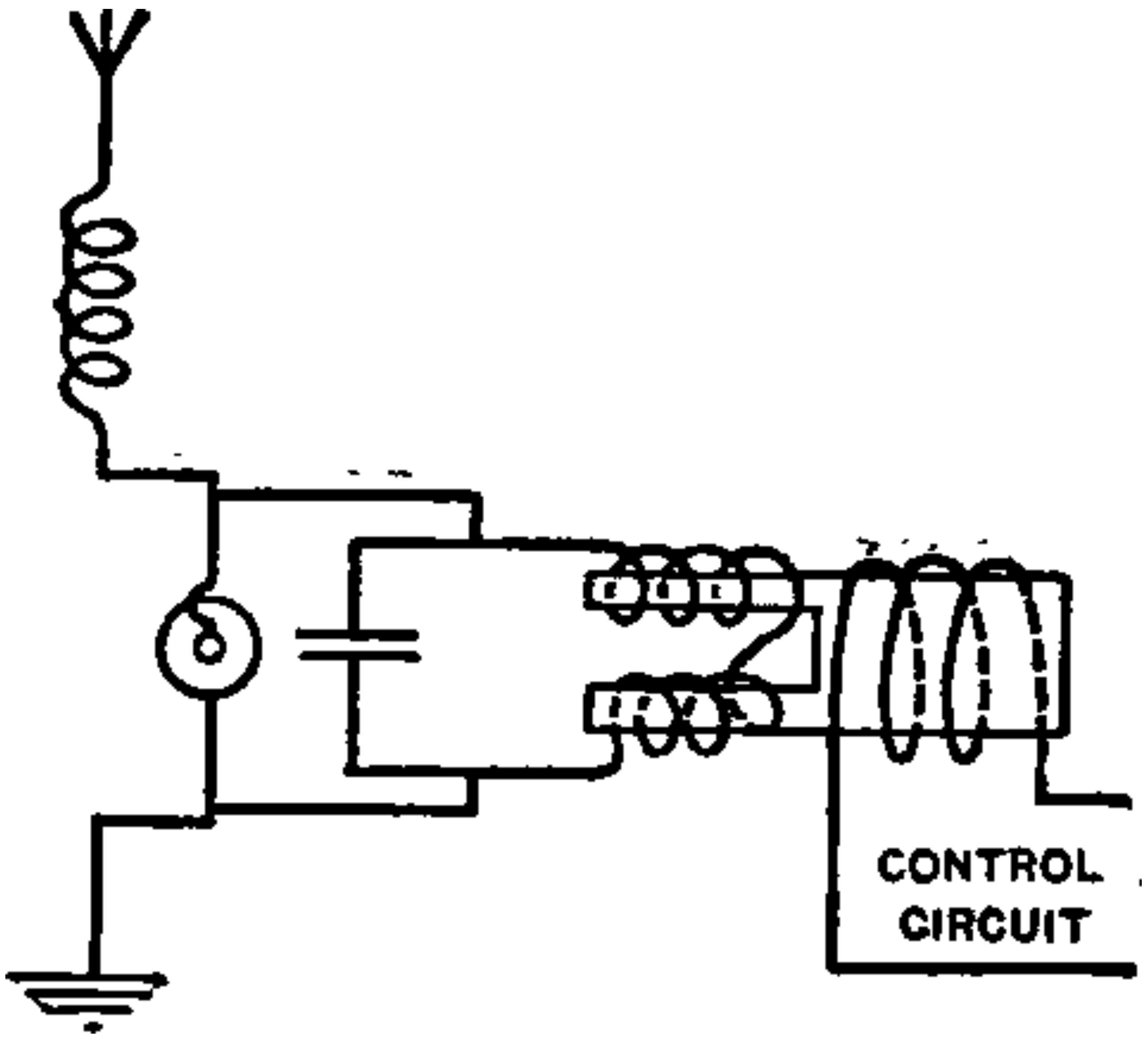

FIG. 1013.

common type of 60 or 25 cycle alternator. With an inductive load, the terminal voltage falls rapidly as the load current increases. With a condenser load the terminal voltage will increase with increased load current, within limits, but after a certain point is reached further attempts to increase the condenser load current will be accompanied by a falling voltage. When the parallel circuit is resonant to the frequency applied only a small current will flow between *A* and *B* through this parallel circuit, because a counter E. M. F. almost equal to the applied E. M. F. will be built up by the current circulating around the closed circuit. As the variable inductance is changed, so that the circuit is no longer resonant, this circulating current will decrease, the counter E. M. F. will decrease, and the current taken by the circuit will increase. If the circuit was thrown out of resonance by making the inductance smaller the result is to produce an inductive load on the generator, and, consequently, reduce the generator voltage. If the circuit is thrown out of resonance by making the inductance larger, the result is to produce a load on the generator such as would be produced by condensers with some resistance. Within limits, this condenser load will cause the voltage of the generator to increase. It is seen from this that variations of current in the control circuit of the magnetic amplifier will be followed by changes in the voltage applied to the antenna circuit, and consequent modulation of the antenna current. Due to various refinements, the circuits actually used with the magnetic amplifier differ somewhat from the preceding elementary circuits. For these differences, and a more detailed explanation of the magnetic amplifier, the reader is referred to A. N. Goldsmith, "Radio Telephony," pp. 192 to 204.

grid to filament represents a loss of power which tends to weaken the oscillations generated. The actual variation of power output with variations of the average grid voltage is shown in Figs. 1015 and 1016 for two different three-element vacuum tubes.* The solid lines are the ordinary plate current—grid voltage characteristics. The dotted lines show the variation of power output with variation of average grid voltage. It is evident that with the circuit used in making these tests the bulb of Fig. 1015 could give only a relatively small (continuous) variation of its output, while the tube used for Fig. 1016 could give a large percentage variation of output, and therefore, act more effectively as a radio telephone transmitter. The condenser C (Fig. 1014) is not a part of an oscillating circuit. Its size is such that it permits the radio frequency to get through, but presents high impedance to audio frequency.

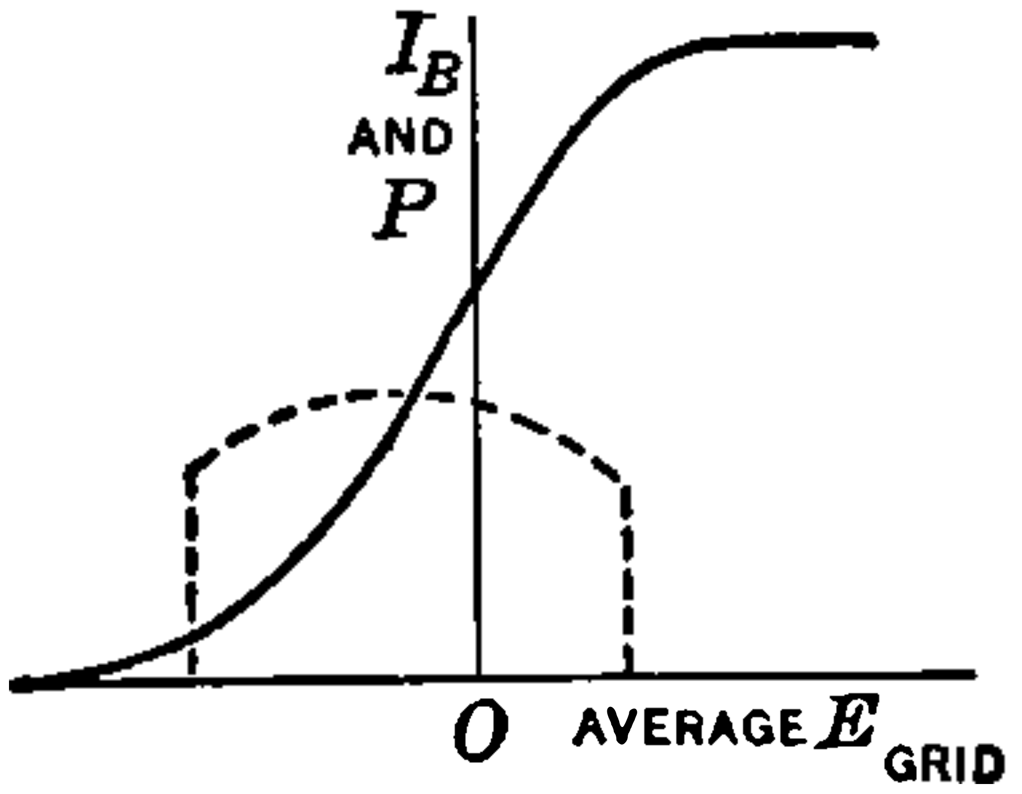

FIG. 1015.

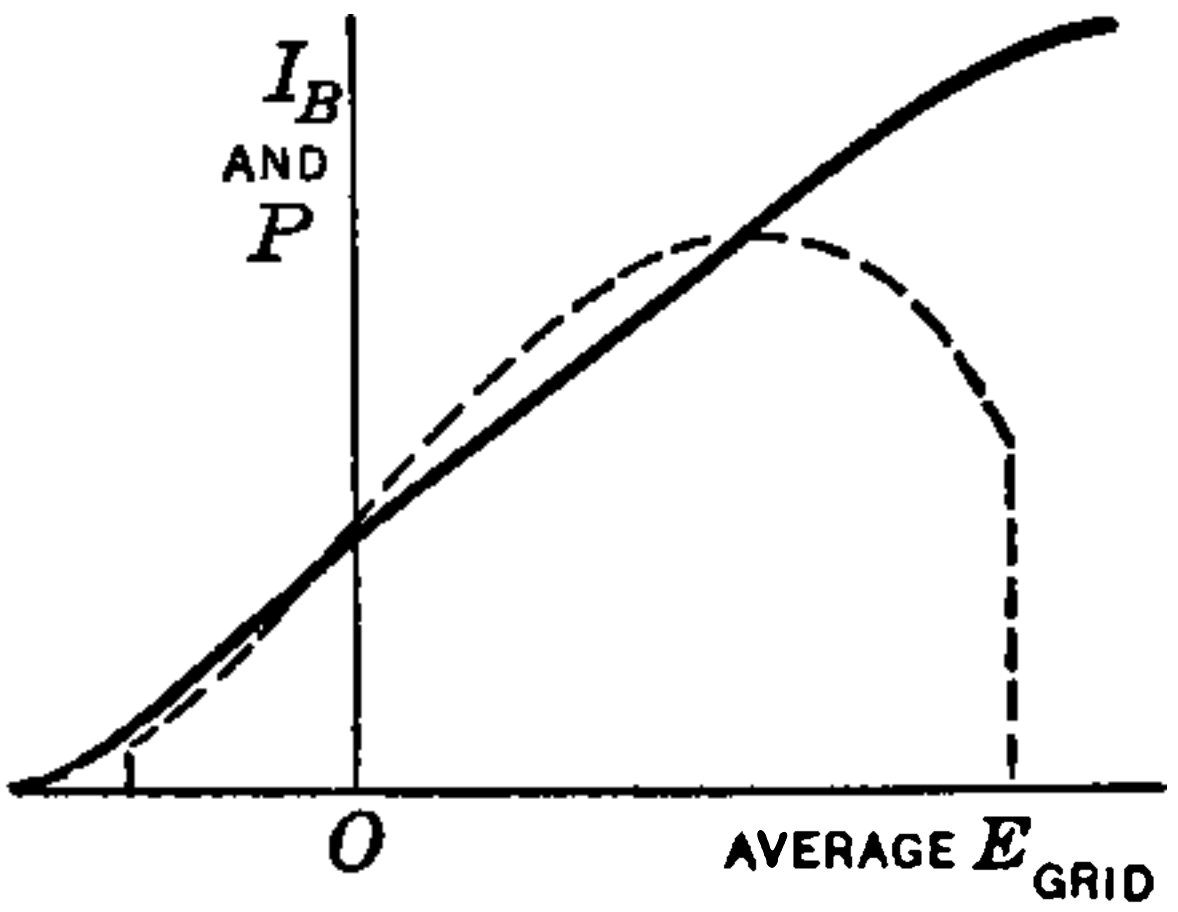

FIG. 1016.

Any detector in common use may be utilized in receiving radio telephone signals. If amplification of the signal is necessary, the ordinary amplifier circuits are satisfactory for moderate amplification. For high amplification at

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* These curves are taken from an article by G. Vallauri in L'Elettrotecnica, June 25, 1917.

audio frequency it may become desirable to increase the natural damping of the audio frequency circuits of the amplifier by putting resistance in parallel with the coils. This prevents the amplifier from responding much more strongly to some one * frequency than to others, and at the same time decreases the tendency of the amplifier to generate oscillations and "howl." Such resistances in parallel with the coils of the amplifier circuits will, of course, decrease the amplification per tube produced by the amplifier system. In the case of amplifiers for loud speaking telephones the vacuum tubes are apt to work with relatively large A. C. voltages applied to their grids. With normal connections this will cause the shape of the A. C. current output from the amplifier to differ appreciably from the shape of the A. C. voltage applied to the grid, due to the plate current-grid voltage characteristic not being evenly approximately straight over any wide range. This difference in wave shape means a change in sound and distortion of speech. This characteristic may be straightened out by inserting a resistance directly in series with the plate circuit, thereby decreasing the distortion.†

Any receiving antenna will receive radio telephone signals, but if long waves are being used, circuits of very low decrement must be avoided to prevent distortion of speech by the flywheel effect of the radio frequency oscillating circuit, which lags in reaching its maximum current and continues oscillating after it should have practically stopped.

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* This one frequency would be the frequency to which the coils with their distributed capacitance and the stray capacitance of the connections are resonant.

† This resistance should have a value at least near one-half of the internal resistance of the plate circuit of the tube.

CHAPTER XI.

RADIO COMPASS.

The effect of an electromagnetic wave on the ordinary antenna does not depend greatly upon the direction from which the electromagnetic wave is coming. A simple way of considering this is to take into account the action of the lines of magnetic flux, which constitutes a part of the electromagnetic wave. It may then be considered that these advancing lines of flux, cutting the vertical part of the antenna, produce the voltage which is effective in producing current in the antenna system. (The return for the antenna current is, of course, through the capacitance of the antenna to ground.) With this approximate idea of the action of the waves on the antenna, it is seen that the waves should produce the same effect on the antenna regardless of the direction, along the surface of the earth, in which the wave is travelling.

In order to determine the direction from which an electromagnetic wave is coming, it is necessary to use some type of antenna, or combination of antennæ, which respond differently to electromagnetic waves coming from different directions. If, as is the case with waves that have travelled a long distance, the front of the electromagnetic wave is inclined from the vertical, an inclined aerial may be more effective than a vertical one if it is inclined in the same direction that the wave is inclined. This fact, in connection with the action of eddy currents produced in the ground by the electromagnetic waves, is thought to explain the action of an inclined or inverted L antenna, which

(that is, 180° out of phase). As the two primary coils are wound in opposite directions, they will now assist each other in their action on the secondary coil, and the maximum result will be produced in the secondary. Evidently, if this whole system could be revolved about a vertical axis, the signals produced by electromagnetic waves from a given direction would vary as the system revolved. The preceding explanations cover the action in the two extreme cases of zero signal and of maximum signal. For any intermediate direction of travel of the wave relative to the receiving system, the voltages produced in the two antennæ would not reach their maximum values at the same time nor half a period apart, for the distance that the wave has to travel after striking one antennæ before it strikes the other would be less than half a wave length. The two voltages will now oppose each other during parts of the cycle, but will not completely cancel each other. The strength of the signal received (from a constant source) would vary as the system revolved, in a manner as indicated in Fig. 1102.

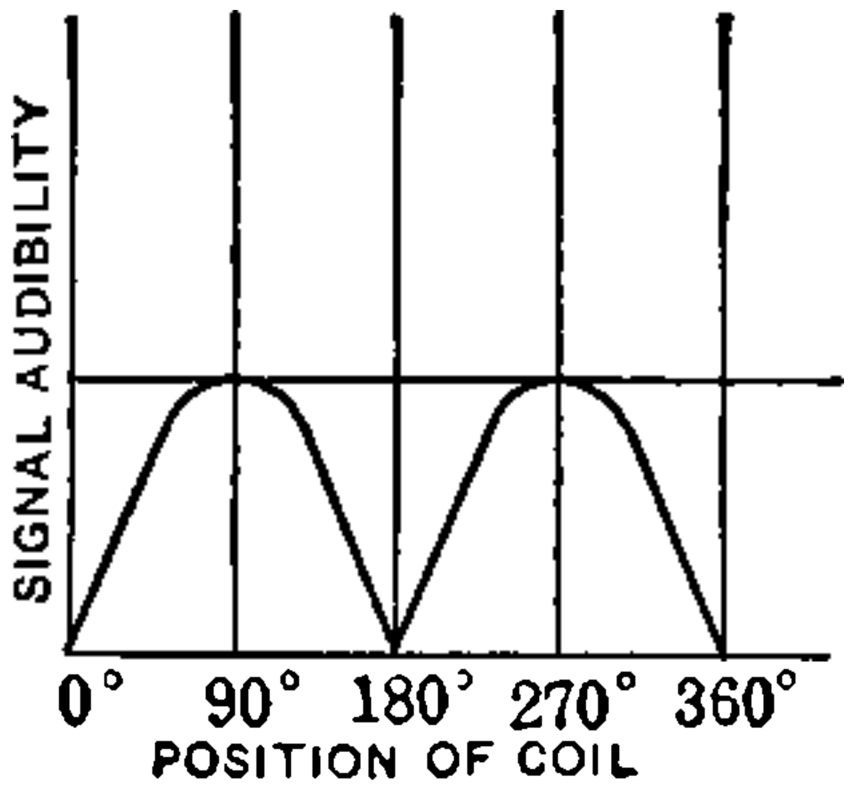

FIG. 1102.

As with any ordinary wave length it would be very inconvenient, if not impossible, to revolve a receiving system as long as one-half wave length, another solution for the determination of direction of travel of the wave is desirable. Following the above theoretical case, one type of solution of this difficulty of moving a large system would be provided by erecting two more antennæ, separated by the same distance, with their horizontal connections running out from the receiving apparatus at right angles to the first two. The two primary coils from one pair of antennæ would be placed together along the same axis, and the two primary coils from the other pair would be placed together outside of the first two and at right angles to them. The magnetic field inside of these four coils will be the resultant produced by the effects of the four currents. It can be shown that with the proper arrangements of the connections, and tuning of the antennæ, the magnetic field inside of these coils due to the antennæ currents will have the same direction as the field striking the antenna system. The strength of this field will be much greater than that of the wave. Its direction can readily be determined by placing the secondary circuit coil inside of the four coils and revolving it. The maximum signal will, of course, be produced when the maximum amount of this field links with the secondary coil, so that maximum signal will be heard when the axis of the coil coincides with the direction of the resultant field. Zero signal strength will be found with the secondary coil at right angles to this position, and as the strength of signal is changing much more rapidly near zero than it is near its maximum, it is possible to locate the zero more accurately than the maximum.

A practical variation of the preceding principles places the vertical parts of the antenna system much less than half a wave length apart. The result of this is that even under the most favorable conditions (for maximum signal) the voltages produced in the two parts of the system are almost in phase, so that the currents produced have almost exactly opposite effects on the secondary, and the resulting signal is correspondingly decreased. This weakness of signal is usually compensated for by the use of either radio frequency amplifiers, audio frequency amplifiers, or both.

Various names have been applied to systems such as these for the determination of the direction from which a signal is coming. Such a system will be referred to here as a "Radio Compass."

The simplest practical form of radio compass consists of a coil a few feet in diameter having but a few turns. This coil is connected in series with a variable condenser to form a closed oscillating circuit. Receiving apparatus is connected directly to it just as though it formed the secondary of an ordinary inductive coupler. Such a circuit is shown in Fig. 1103. If a wave travelling parallel to the axis of the loop strikes this system equal voltages will be produced in each side of the coil *at exactly the same time,* so that the net voltage around the closed loop is zero. If now the coil is turned around a vertical axis to any other position (except 180° from the original), the voltages produced in the two sides of the coil will still be equal, but they will *not* reach their maximum values at exactly the same time (due to the length of time that it takes the advancing wave to travel from one side of the coil to the other), and they will not entirely cancel each other in their effects around the loop. From this it is seen that if the detector system is sufficiently sensitive, a signal will be heard for all positions of the coil except the *two* when the axis of the coil is parallel to the direction of travel of the electromagnetic wave. For the sake of simplicity Fig. 1103 shows only a simple detector. Practically, this simple detector would be supplemented by two or more steps of a vacuum tube amplifier. It should be obvious that in order

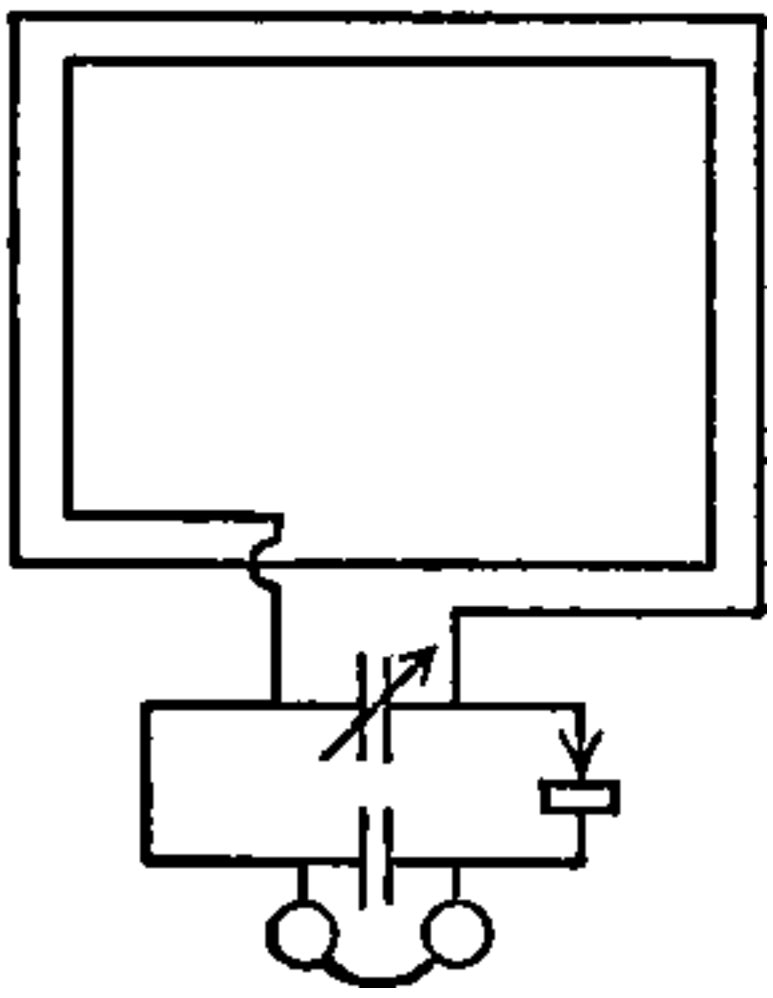

FIG. 1103.

of the coil that was being cut *first* to be changed to the position where it will be cut *last*. This just exactly reverses the direction of the instantaneous values of the resultant voltage around the loop. (That is, it changes the phase relation 180°.) To detect this reversal of direction of the radio frequency current, this current is combined with the current from an ordinary antenna (which is, of course, entirely unaffected by any movement of the coil). If the combination is effected by coupling the antenna to the closed oscillating circuit to which the detector is connected, the antenna current will act to increase the action on the detector at one of the positions at which the simple coil gave a maximum, while at the other position the radio frequency voltage from the antenna will oppose that in the closed circuit, and the signal will be weaker. This makes it possible to tell the difference between the two maxima, and therefore the absolute bearing. The two general methods described above are frequently referred to as bilateral and unilateral respectively. The bilateral being the type that gives two indications. The unilateral being the type that gives one indication. Due principally to the added complications of adjustment of the unilateral method, it is not used for the accurate determination of a bearing. When its use is necessary, the bearing is first determined as accurately as possible with the bilateral apparatus. The direction along the line indicated by the preceding bearing is then determined by the unilateral method. (This, it should be noticed, could readily be determined with an apparatus which was even as much as 45° off the true bearing.) The most favorable condition for the use of the antenna in connection with the loop is given by a coupling to the antenna which makes the signal strength from the antenna constantly equal to the maximum which the loop can produce. The strength of signal due to the loop alone (from Fig. 1102) and the strength of signal from the antenna alone are shown in Fig. 1104. The heavy straight line represents the signal strength from the antenna (which is, of course, independent of the position of the coil). The light line shows the variation of signal from the coil. When the *radio frequency* voltages which produce these two signals are superimposed on one circuit the resultant signal strength is shown by the dotted line. It may be seen that this resultant signal is the result of adding the two signals for 180° of the position of the coil, and of subtracting the coil signal from the antenna signal for the other 180° of coil position. The reason for adding in one case and subtracting in the other, as has already been explained, is that in one case the *radio frequency* voltages are in the same direction, while in the other case they oppose each other.

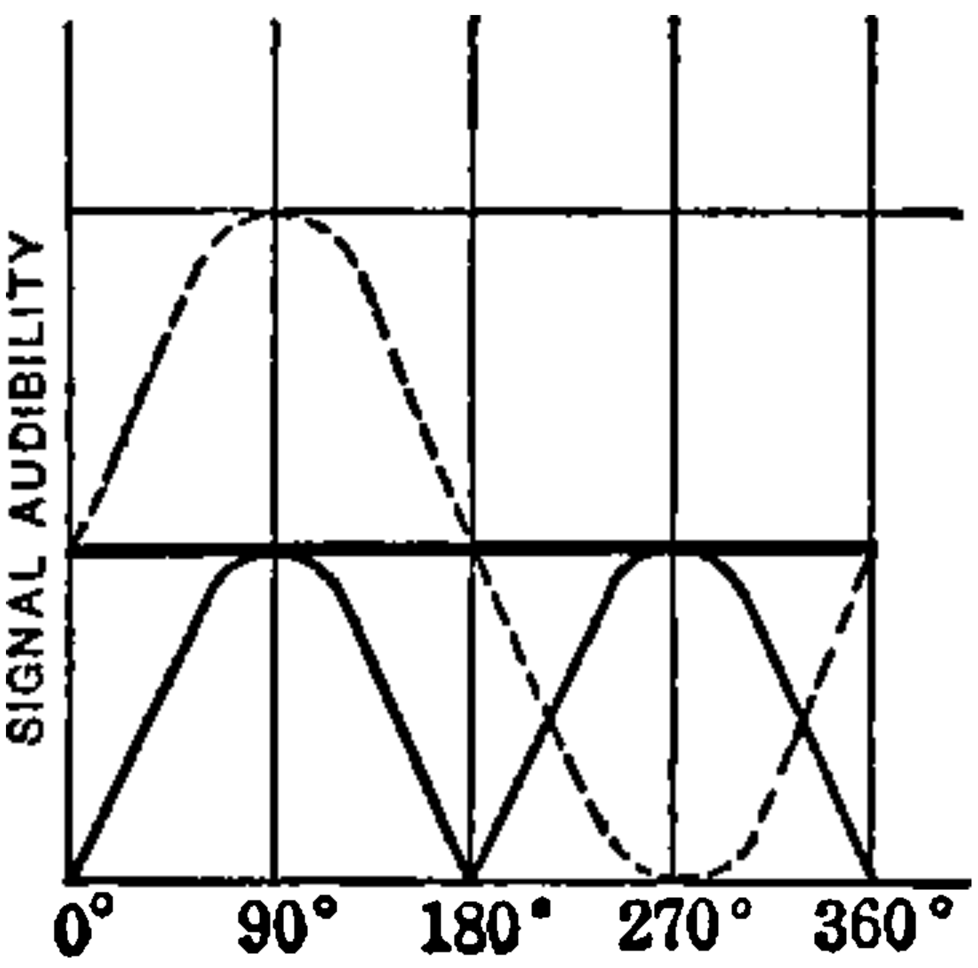

FIG. 1104.

It was assumed in the preceding paragraphs that the voltage produced by the antenna (in the circuit to which it is coupled) would be either directly in phase with or in direct opposition to the net voltage produced by the coils. To get a close approximation to this the tuning of the circuits to the received wave length must be very accurate.* This

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* In addition to this, to permit the voltage from the antenna to exactly cancel the voltage induced in the coil, the decrement of the current in the antenna circuit must be the same as that of the transmitted electromagnetic wave. Otherwise one voltage would reach zero before the other.

introduces a possibility of large errors in the unilateral method.

Another assumption that has been made in the preceding explanations is that the electromagnetic wave travels in a so-called straight line (following the curvature of the earth, however). For the shorter wave lengths in common use this seems to be true, except for the disturbing effects of metal in the neighborhood of the receiving loop. The disturbing effects of metal may for convenience be divided into two varieties. The action of the first variety may be thought of as being similar to the action of some stationary object in the path of a water wave (when the object is *not* large compared to the wave length). Fig. 1105 represents a series of water waves travelling from the top of the page toward the bottom. In the center of the figure is a stationary obstacle. It is well known that under these circumstances part of the wave will be distorted when it strikes the obstacle, and that the waves will close in again behind the obstacle in a manner as illustrated. The important point to be understood is that if an observer stationed at the point A can see only the small part of the wave in his immediate neighborhood, it appears to him that the wave is travelling in the direction indicated by the arrow. This is the situation in the case of the radio compass, for the measurement to determine the direction of travel of the wave is made on a relatively very small portion of the wave front. This particular type of trouble causes the determination of bearing made by the radio compass to be inaccurate, but does not interfere with the accuracy of making a setting of the loop, except as it weakens the signal for

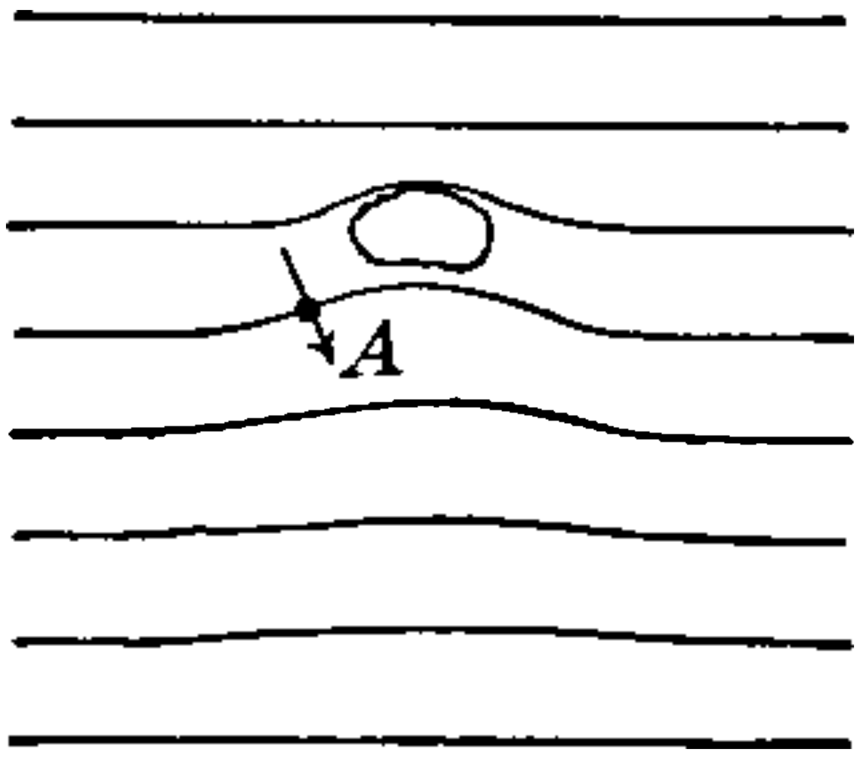

FIG. 1105.

It has long been known that the transmission of electromagnetic waves at night is subject to erratic variations (as judged by the intensity of signal at the receiving station). This has been thought to be due, at least in part, to reflection of the waves from some upper strata of the air which is ionized so as to be partially conducting. This hypothesis finds evidence in its favor in the direction of travel of long waves at night. Observations on stations of known location at moderate distances have shown that at night these long waves frequently do not arrive at the radio compass from the direction of the sending station, and furthermore the direction from which they do arrive may change by relatively large amounts in a short time. This action might be explained by assuming that part of the wave arriving at the radio compass started away from the transmitting station in a direction appreciably different from that of the radio compass, and that after reaching high altitudes it was reflected from a strata of ionized air which had been inclined at an angle by air currents. As such errors as these are not constant, it appears impossible to correct for them. This same condition is encountered to a much smaller extent in the day time. This source of error seems to be negligible for short wave lengths.

Another source of error encountered in radio compass installations is due to the action of the electromagnetic waves directly on the wiring and coils of the receiving apparatus. Where it is desired to get the most accurate results obtainable this is reduced to a negligible minimum by surrounding the receiving apparatus and connections (but of course not the loop) by sheet metal or wire netting and grounding this cage.

As was mentioned at the end of the chapter on Receiving Apparatus, "static" and the reduction of its effects will be treated at this point, because of the impossibility of understanding the principle involved in some of the apparatus without understanding the radio compass.

"Static"* is one name which is used to cover the electrical disturbances coming from a distance, and not created by transmitting apparatus, which are encountered in the reception of radio signals. It has been found that static may be divided into a number of varieties. Those due to snow storms and lightning occur so relatively infrequently as to be of negligible consequence (in spite of the fact that lightning in the neighborhood of an antenna produces the most violent disturbances to which it is subjected). Three other major types are recognized which Eccles has classified under the names of "grinders," "clicks," and "hissing." The last of these types, due generally to an actual discharge from the antenna to earth, produces very little disturbance and is not present when antennæ are used which have no earth connection. Usually both clicks and grinders are present, with the latter creating most of the interference. Grinders make themselves evident as a sort of continuous rattle with occasional heavier crashes. Clicks are relatively widely spaced crashes. Grinders and clicks appear to be produced by electromagnetic waves either of very high damping, or impulses which are not oscillatory at all. The result of this is that upon striking an oscillating circuit they tend to set it into oscillation *at the wave length to which it is tuned,* by impact

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* Much of the following information concerning static and the reduction of its effects is taken from an article by Roy Weagant, chief engineer of the Marconi Wireless Telegraph Co. of America, in the June, 1919, number of the "Proceedings of the Institute of Radio Engineers."

excitation, in the same way that a bell is started by hitting it with a hammer. For this reason, disturbances of this kind cannot be tuned out. Mr. Weagant has made the very important discovery that grinders act as though they were travelling in a *vertical* * direction, and therefore at right angles to any ordinary signal. Clicks travel horizontally and seem to come at random from first one direction and then another in rapid succession, so that a radio compass would give no directional indication on them.

The use of loose coupling somewhat decreases the effects of any highly damped signal, and therefore has some effect on static. Simple loops also receive somewhat less static in proportion to the signals than an ordinary antenna, due in part to the fact that clicks from some directions are much reduced in strength on the radio compass principle. In addition to drowning out the signals, one of the bad effects of static is that loud crashes temporarily lessen the sensitiveness of the ear for weak signals. This feature may to a large extent be overcome by using special arrangements of the detector system, giving results as illustrated in Fig. 1107. The type in which a certain maximum signal strength is not exceeded in spite of the strength of the incoming wave is illustrated by certain vacuum tube systems the maximum possible output of which (under the conditions of oper-

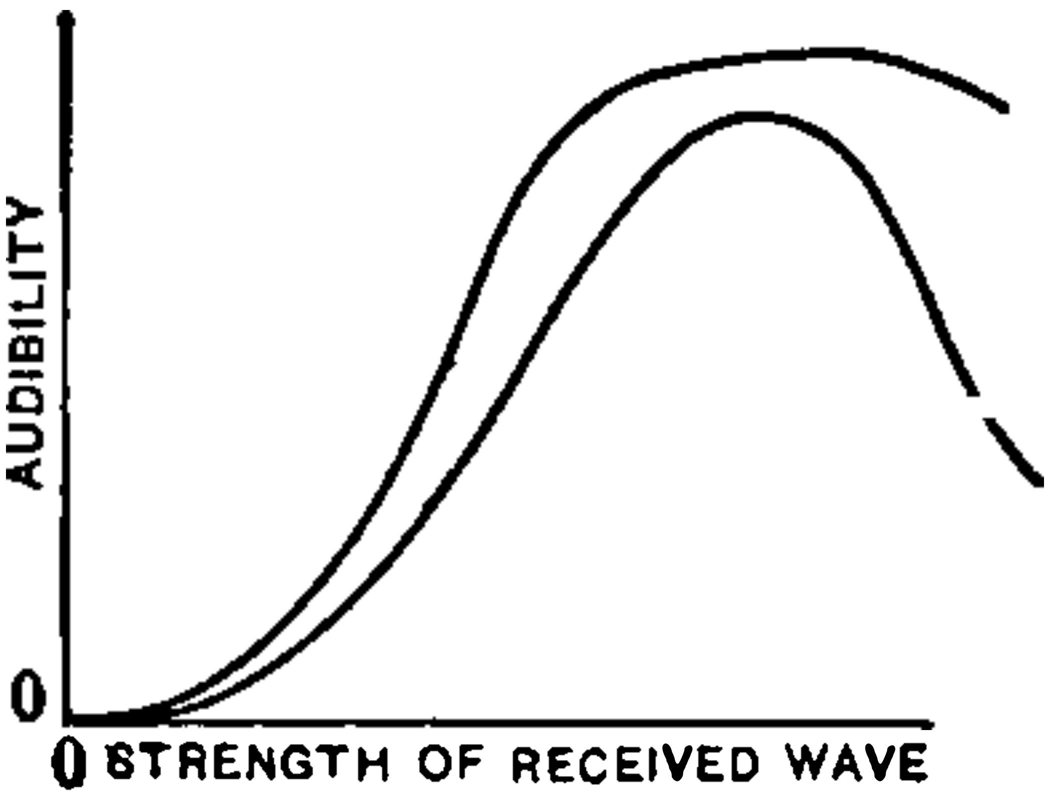

FIG. 1107

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* It should be noted that while Mr. Weagant emphasizes the fact that grinders act simultaneously on different parts of an antenna system in the same horizontal plane, as would be the case if the transmission were vertical, he does *not* state that he has *proved* the transmission to be vertical.

voltages produced by these waves reach their maximum values at the same time and exactly oppose each other. If the plane of the coils is not at right angles to the direction of travel of the signal waves, the voltages produced by the signals do not reach their maximum values at the same time in the two coils so that there is some resultant signal left over (depending upon the distance that the coils are apart).*

Other systems based upon causing the voltages produced in two parts of the system by static to oppose and cancel, while not entirely canceling the signal, have proven capable of considerable reduction of static. A particularly valuable discussion of a number of systems of this type is contained in an article by Lieutenant-Commander A. Hoyt Taylor, U. S. N. R. F., in the December, 1919, "Proceedings of the Institute of Radio Engineers."

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* If the dimensions of the coils and distances between them are both small compared to half a wave length, the voltage in one coil is the difference between two equal and nearly opposite voltages, and the final resultant is the difference between two equal and nearly opposite resultant voltages from the coils, thus giving an enormous reduction in the strength of signal available. Either enormous amplification, or dimensions approaching half a wave length, or more practicably a compromise, is necessary to obtain signal audibilities comparable to those directly from an ordinary antenna.

CHAPTER XII.

MEASUREMENTS AND FORMULÆ.

1. Energy Relations in an Inductive Circuit.—If i represents the instantaneous value of the current in an inductive circuit at any instant and E the impressed E. M. F. and R the resistance of the circuit, then Ei will be the instantaneous value of power expended. A portion of E is expended in sending a current i through the resistance R and is equal to Ri. The remaining part of E is expended in overcoming the E. M. F. of self-inductance and is equal to $L\,di/dt$. Therefore $E=Ri+L\,di/dt$. Multiply through by idt. $Eidt=Ri^2dt+Lidi$. Hence,

$$\int_0^t Eidt=W=\int_0^t Ri^2dt+\int_0^t Lidi \qquad (1)$$

The term $\int_0^t Ri^2dt$ represents the energy spent in heat, and $\int_0^t Lidi=\frac{LI^2}{2}$ represents the energy stored up in the magnetic field while the current increases from 0 to I. If the current is gradually decreased, the energy $1/2\ LI^2$ is returned to the circuit, due to its action in tending to prevent the decrease, but if the circuit is suddenly broken a very high induced E. M. F. is created and the energy is expended in sparking across the contacts and volatilizing the metal.

2. Frequency of Oscillation in a Series Circuit.—The equation of frequency in an oscillating circuit as originally derived by Lord Kelvin is based on the law, enunciated by Kirchhoff, that in a circuit in which current is flowing the sum of the instantaneous values of E. M. F.'s is equal to zero. In an oscillating circuit, then, $Ri+L\,di/dt+q/C=0$. Since $i=dq/dt$ and $di/dt=d^2q/dt^2$ the equation above becomes

$$\frac{d^2q}{dt^2}+\frac{R}{L}\cdot\frac{dq}{dt}+\frac{q}{LC}=0.$$

The solution of this differential equation gives us a value for q, hence also for i. It can be shown by mathematical deduction from the above equation that if the value of R is greater than the $\sqrt{4L/C}$, the charge on the condenser dies away gradually, as time increases, in such a manner that the current is always in the same direction. Thus no oscillations take place. If the value of R is less than above-named value, the differential of q has positive and negative values, or the current in the circuit is reversed periodically, as time increases. The equation for current is of the form below,

$$i=\frac{2E}{\sqrt{\frac{4L}{C}-R^2}}\cdot\epsilon^{\frac{-RT}{2L}}\sin\left\{\left(\sqrt{\frac{1}{LC}-\frac{R^2}{4L^2}}\right)t\right\}$$

in which E is the initial value of the E. M. F. across the condenser, in volts, L is the inductance in henries, C the capacity in farads, R the resistance in ohms. This is the general form of an equation for an alternating current of decreasing amplitude, $i=p\sin\omega t$ where

$$\omega=2\pi f=\sqrt{\frac{1}{LC}-\frac{R^2}{4L^2}}.$$

From this

$$f=\frac{1}{2\pi}\sqrt{\frac{1}{LC}-\frac{R^2}{4L^2}}.$$

The power may be measured calorimetrically or, as is usually done in practice, a known resistance is substituted for R and placed in the calorimeter and direct current sent through, and adjusted until the final temperature is the same as with the unknown resistance. By comparison of the results the unknown resistance is determined.

The substitution method is convenient and rapid and is suitable for rough measurements. It involves the use of a resistance standard, and due to the fact that when substitutions are made in a circuit, stray E. M. F.'s are electrostatically induced, this method is not as accurate as some others.

The procedure under the third and fourth methods is practically the same, but since a variable reactance, such as a calibrated condenser, is more often available than a resistance standard, the latter method will be described in full. This method is sometimes called the decrement method, but the name is no more applicable to this than to the other methods, since all measure decrement in the same sense that this does. That the method primarily measures resistance rather than decrement is seen from the fact that in its simplest and most accurate form it utilizes undamped current, which has no decrement.

An ammeter is connected in series with the circuit whose resistance is to be measured and the circuit loosely coupled to a source of undamped oscillations. The circuit is tuned to resonance and the current measured by ammeter. The reactance, which is zero at resonance, is now changed to some other value X_1. The change can be effected by varying the inductance or the capacity. Calling the currents at resonance and with added reactance I_r and I_1 respectively, we get the following equations, assuming the applied E. M. F., E, to remain constant,

$$I_r^2 = \frac{E^2}{R^2}$$

$$I_1^2 = \frac{E^2}{R^2 + X_1^2}.$$

From these it follows that

$$R = X_1 \sqrt{\frac{I_1^2}{I_r^2 - I_1^2}}. \tag{1}$$

If the reactance is varied by such an amount as to make the quantity under the radical sign equal to unity, the equation reduces to

$$R = X_1.$$

When the reactance is varied by changing the setting of a variable condenser, equation (1) becomes (2) given below. This reduction is effected by substituting for X_1 its value, in terms of capacity, or $\frac{1}{\omega C_r} - \frac{1}{\omega C_1}$ where C_r and C_1 represent capacity at resonance and with changed reactance respectively.

$$R = \frac{\pm (C_r - C_1)}{\omega C_r C_1} \sqrt{\frac{I_1^2}{I_r^2 - I_1^2}}. \tag{2}$$

For variation of inductance (1) becomes, by similar reduction (3),

$$R = \pm \omega (L_1 - L_r) \sqrt{\frac{I_1^2}{I_r^2 - I_1^2}}. \tag{3}$$

The reactance may be varied by changing the frequency of the source but care must be taken that, with the change of frequency, the E. M. F. is maintained constant. See equation (4).

$$R = \frac{\pm L(\omega_1^2 - \omega_r^2)}{\omega_1} \sqrt{\frac{I_1^2}{I_r^2 - I_1^2}}. \tag{4}$$

If we observe equal values of current on the two sides of the resonant value I_r and call the corresponding values of capacity C_1 and C_2, the equation becomes

$$R = \frac{1}{2\omega} \frac{C_2 - C_1}{C_2 C_1} \sqrt{\frac{I_1^2}{I_r^2 - I_1^2}}. \tag{5}$$

The above formulæ are rigorous for undamped E. M. F. and are sufficiently accurate for damped E. M. F. when the damping is small.

4. Decrement Calculation.—By Kirchhoff's law the sum of the instantaneous values of the E. M. F. around a complete circuit in which free oscillations are taking place must be equal to zero. Hence, in a circuit containing inductance *L*, capacity *C* and resistance *R*,

$$L\frac{di}{dt} + Ri + \int\frac{idt}{C} = 0.$$

The solution of this equation gives, when the resistance is not very large, an equation for instantaneous current as follows: $i = I_0 \epsilon^{-\frac{Rt}{2L}} \sin \omega t$, in which I_0 = initial current, t = time elapsed since beginning of wave train, $\omega = 2\pi$ times the frequency, $\frac{R}{2L}$ = damping factor, usually indicated by a, which by definition is the product of frequency times log decrement. The relation between the damping factor and the log decrement can be shown mathematically as follows: If the time of one complete oscillation is represented by $T = 2\pi/\omega$, the ratio of successive current maxima (sin

If $I_1^2 = \frac{1}{2}I_r^2$, the expression under the radical sign becomes unity, simplifying the formulæ.

These formulæ are correct only when, (1) the coupling between the circuits is so loose that the secondary does not appreciably affect the primary, (2) δ' and δ are both small compared to 2π, and (3) the ratio $\frac{C_r - C_1}{C_1}$ and the corresponding ratios are small compared to unity.

5. The Decremeter.—As previously explained under the reactance-variation method of decrement calculation, if the two values of current observed are such that $I_1^2 = \frac{1}{2}I_r^2$, the equation for decrement becomes (when capacity is the variable),

$$\delta' + \delta = \pi \frac{\pm (C_r - C_1)}{C_1}.$$

A certain value of decrement therefore corresponds to that displacement of the condenser's moving plates which varies the capacity by an amount equal to $(C_r - C_1)$. The displacement will in general be different for different values of the total capacity in the circuit. At each point of the condenser scale any displacement of the moving plate which changes the square of the current from I_r^2 *to* $1/2\ I_r^2$ means a certain value of $(\delta' + \delta)$. A special scale may, therefore, be attached to any condenser with graduations so marked on it that the difference between two settings of the condenser, when the square of the current is I_r^2 and when it is $1/2 I_r^2$, is equal to the total decrement. A wave meter with such a scale attached is called a decremeter. The spacing of the graduations at different parts of the scale depends upon the relation between capacity change and displacement of the moving plates. In order to measure accurately small decrements a uniform decrement scale is desirable. Such a scale can be used with a condenser whose plates are so shaped that the percentage change of capacity per scale division is constant throughout the range. A Kolster type condenser fulfills this condition and is used in the Navy type decremeter. The scale is usually calculated to fit the equation below which applies when two observations are taken, for equal values of current, on either side of the resonant point.

$$\delta' + \delta = \pi \frac{C_2 - C_1}{C_2 + C_1} = \pi \frac{\lambda_2{}^2 - \lambda_1{}^2}{\lambda_2{}^2 + \lambda_1{}^2}.$$

The decrement scale may be attached directly to the condenser or, as is usually done, to a separate shaft geared to the moving plates by a ratio sufficiently high to open out the decrement scale, permitting very precise measurements. The decrement obtained from this scale is the total decrement, hence it is necessary to know the decrement of the instrument itself. By simple subtraction the decrement of the circuit under measurement is obtained. The operation of the instrument is as follows: The condenser setting is varied until the deflection of the current-squared meter is a maximum, then varied until one-half of this deflection is obtained. The movable decrement scale is then set at zero and clamped to its shaft, and the condenser varied until the same deflection is obtained on the other side of the resonant point. The reading of the decrement scale then gives the total decrement. Subtract from this the decrement of the instrument and the remainder is the decrement of the circuit being measured.

Inaccurate results will be obtained if the frequency of the source is not constant, as may be the case when the oscillations are produced by means of an arc; also when the coupling of the two circuits is too close. Under both conditions the effect is that of broad tuning and it is difficult to determine the point of exact resonance.

6. Calculation of Capacity.—In the following formulæ for capacity,

A—Area of one plate (one side) in square centimeters.
t—Thickness dielectric in centimeters.
K—Specific inductive capacity or dielectric constant. (K equals unity for air and varies between 1 and 10 for substances ordinarily used for dielectrics.)
C—Capacity in micromicrofarads (farads $\times 10^{-12}$).

PARALLEL PLATE CONDENSER.

$$C = .0885KA/t \text{ mmf.}$$

With N similar plates, alternate ones in parallel and dielectric between,

$$C = .0885K(N-1)A/t \text{ mmf.*}$$

ISOLATED SPHERE.

If d is the diameter of the sphere, in centimeters,

$$C = .556d \text{ mmf.}$$

TWO CONCENTRIC SPHERES.

If r_1 = inner radius of outer sphere, r_2 = outer radius of inner sphere

$$C = 1.112Kr_1r_2/(r_1 - r_2) \text{ mmf.}$$

*** It should be observed that it is really the area and thickness of *active dielectric* which determines the capacity of the condenser.**

$$L \text{ (in henries)} = \frac{cm^2}{b+c+R} \times \frac{F'F''}{10^9},$$

in which

cm—Length of conductor in centimeters.

b—Length of coil, parallel to axis.

c—Thickness of winding, or difference between inside and outside radii. (In single layer coils of fine wire this term may be neglected, with little inaccuracy.)

R—Outside radius of coil.

F' and F'' are empirical coil-shape factors which depend upon the relative values of the different dimensions and are determined as follows:

$$F' = \frac{10b+12c+2R}{10b+10c+1.4R}.$$

$$F'' = 0.5 \log_{10}\left(100 + \frac{14R}{2b+3c}\right).$$

All dimensions are in centimeters.

8. Antenna Constants.—In order to determine experimentally the inductance and capacity of an antenna, two loading coils of different and known inductance are successively inserted in the antenna, and the wave lengths determined for which the antenna is in resonance. The source of oscillations may be the spark circuit, connected as for sending, and a standardized wavemeter is used to determine the frequency of the source. The procedure is as follows: Insert one of the coils of known inductance, L', in series in the antenna, couple antenna circuit loosely to the spark circuit and by varying the frequency of the source bring the two circuits into resonance as indicated by the ammeter in the antenna circuit. Detune the antenna and measure the frequency, or wave length, of the source. Repeat with coil L'' in the antenna. Since the total inductance of the antenna circuit is the sum of the natural inductance of the antenna, L, and the inductance of the coil, L' or L'', and the capacity is practically that of the antenna alone, we have, using the simple formula for lumped inductance and capacity,

$$\lambda'=1884\sqrt{(L'+L)C},$$
$$\lambda''=1884\sqrt{(L''+L)C}.$$

Eliminating C between these two equations and solving for L we have

$$L=\frac{L''\lambda'^2-L'\lambda''^2}{\lambda''^2-\lambda'^2}.$$

From the known values of L' and L'' and the observed wave lengths, λ' and λ'', we can compute the inductance of the antenna, L. By substituting this value of L in one of the original equations (preferably in the one corresponding to the larger inductance coil) we obtain the value of C, the capacity of the antenna.

9. Transmission Formulæ.—The following transmission formulæ are taken from publications of the Bureau of Standards and are given here to assist the student in gaining an idea of the magnitude of effects to be expected under various conditions, as to distance and types of antennæ, etc. In the formulæ, I represents current, h, height of antenna or coil, d, distance between sending and receiving stations, λ, wave length. The subscripts r and s refer to the receiving and sending stations respectively. R stands for the resistance of the receiving circuit. All lengths are expressed in meters. The current in the receiving antenna is given in terms of the sending current, heights of antennæ, distance apart, resistance of the receiving antenna, and the wave length used.

If the waves are sent out on a simple flat top antenna and received on a similar one,

$$I_r = \frac{188 h_s h_r I_s}{R\lambda d}.$$

If the waves are sent out by a simple flat top antenna and received on a closed coil,

$$I_r = \frac{1184 h_s h_r l_r N_r I_s}{R\lambda^2 d},$$

in which l_r is the length of the receiving coil and N_r is the number of turns of wire with which it is wound.

If the waves are sent out on a closed coil and received on a simple antenna, we have

$$I_r = \frac{1184 h_s l_s h_r N_s I_s}{R\lambda^2 d},$$

in which l_s is the length of the sending coil and N_s is the number of turns of wire on the coil.

If the waves are sent out on a closed coil and received on a similar one, we have

$$I_r = \frac{7450 h_s l_s h_r l_r N_s N_r I_s}{R\lambda^3 d}.$$

In all of these formulæ, if d is greater than **100** kilometers, the result should be multiplied by the factor $\epsilon^{-0.000047 d/\sqrt{\lambda}}$, in which d and λ are in meters and ϵ equals 2.718.

From the above formulæ it is readily seen that, for short distances the current in the receiving antenna varies directly as the heights of the antenna and the sending current, and inversely as the distance and the wave length

cuit is varied. This sudden change is detected, usually, by having a telephone in series with the "B" battery of the generating circuit. When the sudden change of current occurs there is one click in the telephone receiver. On changing the adjustment of the circuit in the opposite direction another click is obtained just the other side of the resonant setting. The looser the coupling between the circuits the nearer to resonance will these clicks occur.* Usually it is possible to bring the clicks so very close together that they almost merge into one. Resonance is then determined with a very high degree of accuracy, at the setting of the condenser half-way between the two clicks. If, for instance, it is desired to determine by this system the wave length to which a certain circuit is resonant the procedure would be as follows: First, couple the generating circuit to the circuit whose wave length is to be determined. Then adjust the coupling between the two circuits until the clicks which are obtained by changing the wave length adjustment of the generating circuit are very close together. Finally, set the adjustment of the generating circuit just half-way between the clicks. The generating circuit is now adjusted to generate exactly the wave length to which the unknown circuit is resonant. Now remove the unknown circuit and couple a wave meter (preferably with no crystal detector or other attachments) to the generating circuit. Repeat the preceding adjustments for resonance, changing the setting of the wave meter and not touching the generating circuit. The setting of the wave meter half way between the clicks, which

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* Up to a certain point, beyond which no click occurs.

are close together, will accurately determine the wave length to which the unknown circuit was resonant. It should be known that the addition of detectors, buzzers, etc., to the wave meter affects it accuracy. This method requires no attachments whatever, therefore avoids this source of inaccuracy. For this reason this method is often used in calibrating wave meters. The only limitation to the use of this method is the fact that it will not indicate at all if the decrement of the unknown circuit is high. The action occurring in this circuit may be understood with the aid of Fig. 1201. The oscillating circuit at the right is so placed as to be inductively coupled to L_g. The *amount* of effect which the second circuit will have on the generating circuit depends upon the amount of current produced in the second circuit. The *nature* of the effect which the second circuit

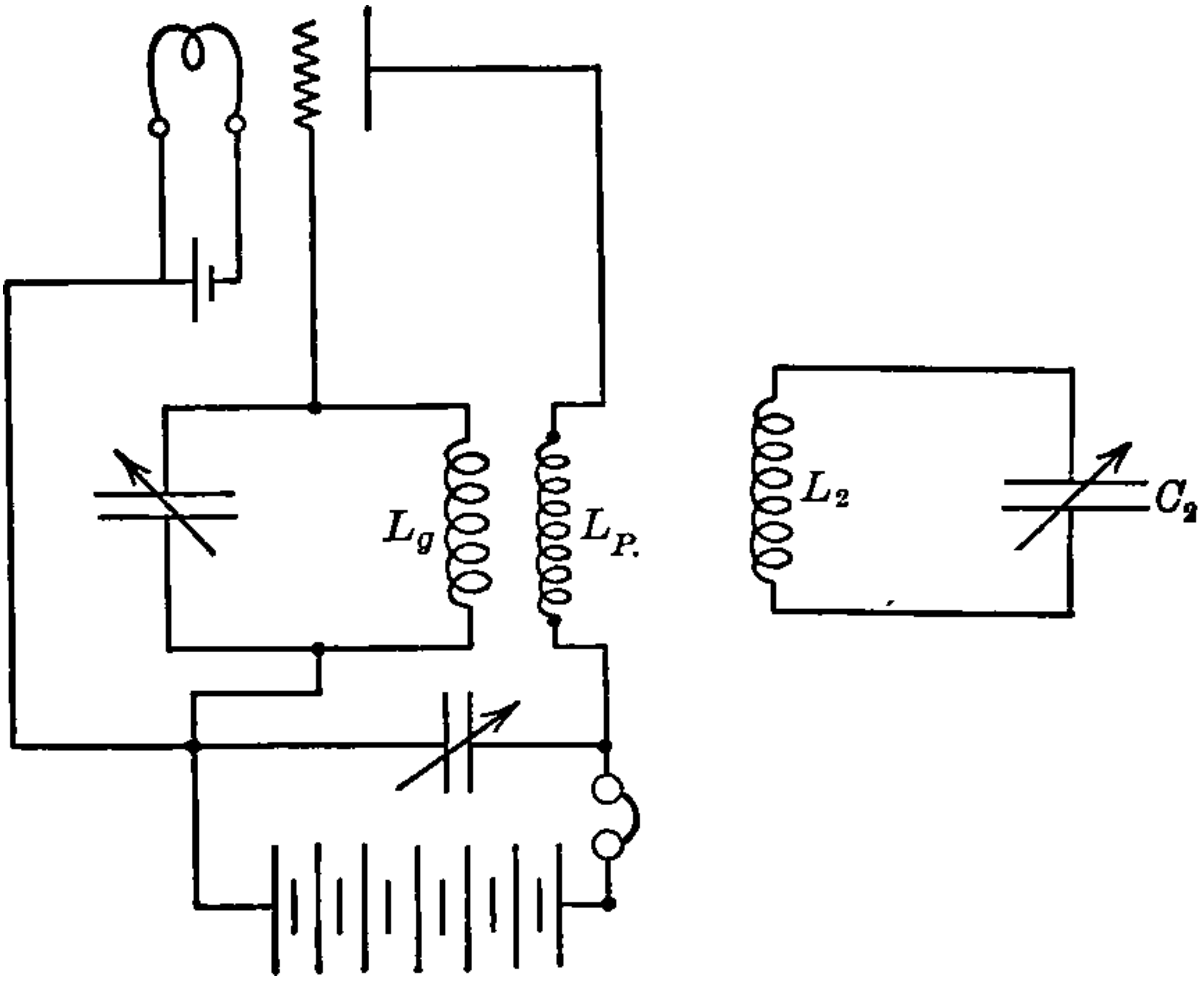


FIG. 1201.

produces on the generating circuit depends upon the phase relation of the secondary current to the voltage which produces it. If the generated frequency is higher than the frequency to which the second circuit is resonant, the reactance of C_2 is less than that of L_2 and the current lags nearly 90 degrees behind the voltage. When the second circuit is adjusted very nearly to resonance to the generated frequency, the two reactances are very nearly equal, the resistance of the second circuit determines the flow of current, and the current is nearly in phase with the voltage. Finally, if the generated frequency is lower than that to which the second circuit is resonant, the reactance of C_2 is greater than that of L_2 and the current leads the voltage nearly 90 degrees. In these three cases the results on the generating circuit are equivalent to putting, (1) an inductance in parallel with L_g, (2) a resistance in parallel with L_g, (3) a capacitance in parallel with L_g. (1) increases the frequency generated, (2) does not greatly affect the frequeney generated, (3) decreases the frequency generated.

Starting with the secondary circuit tuned to a frequency lower than that being generated, if the difference is great, very little current flows in the secondary, and there is correspondingly very little effect on the generating circuit. Now as the secondary circuit is tuned to higher frequencies (approaching the frequency which was being generated), the current in the second circuit becomes larger and the frequency being generated *increases*. For this reason, when the second circuit comes to resonance with the frequency which was originally being generated, the frequency actually being generated will be higher than this. A small further increase in the frequency to which the second circuit is tuned will result in the second circuit closely

approaching the generated frequency. At this point the reaction of the second circuit ceases to produce the increase of generated frequency as condition (2) above has been reached. The generated frequency then tends to return to the original value, but just as soon as it does the frequency being generated is lower than that to which the second circuit is tuned, and consequently the generated frequency falls still lower. It is at the instant that this sudden change takes place that the click occurs. When changing the adjustment in the reverse direction an exactly similar series of changes occurs. If the decrement (that is, the value of the resistance as compared to the reactances) of the second circuit is high the phenomena are confined principally to condition (2) above, and the sudden change does not occur. It should be noted that when an appreciable amount of power is transferred to the second circuit to maintain a large current in it, the generated current falls off somewhat. The changes actually occurring are shown in Fig. 1202. It is the *change* in the current generated which affects the average value of the plate current, and therefore affects the telephone.

11. Wave Length or Frequency.—Wave length or frequency is determined by one of the following formulæ, depending upon data available:

$$\lambda = V/f = 3 \times 10^8/f$$
$$= 1884 \sqrt{LC}$$

Here λ is the wave length in meters, V the velocity of propagation of electromagnetic waves (3×10^8 meters per second), f is cycles per second, L is total effective inductance of an oscillating circuit *in microhenries,* and C is total effective capacitance *in microfarads.*

APPENDIX A.

THE INSTITUTE OF RADIO ENGINEERS.

REPORT OF THE COMMITTEE ON STANDARDIZATION.

Definition of Terms.

NOTE.—Terms are generally arranged alphabetically according to the noun referred to.

1. Absorption, Atmospheric: That portion of the total loss of radiated energy due to atmospheric conductivity.
2. Ammeter, Hot Band or Hot Wire: An ammeter dependent for its indications upon the change in dimensions of an element which is heated by a current through it.
3. Ammeter, Thermo: An instrument for measuring current, depending for its indications on the voltage generated at the terminals of a thermo junction heated either directly or indirectly by the current to be measured.
4. Amplifier or Amplifying Relay: An instrument which modifies the effect of a local source of energy in accordance with the variations of received energy; and, in general, produces a larger indication than could be had from the incoming energy alone.
5. Amplification, Coefficient of: The ratio of the useful effect obtained by the employment of the amplifier to the useful effect obtained without that instrument.
6. Antenna: A system of conductors designed for radiating or absorbing the energy of electromagnetic waves.
7. Antenna, Directive: An antenna having the property of radiating a maximum of energy in one (or more) directions.
8. Antenna, Flat Top: An antenna having horizontal wires at the top covering a large area.
9. Antenna, Harp: An antenna having an approximately vertical section of large area and considerable width.

10. **Antenna, Inverted L:** A flat top antenna in which the leading down wires are taken from one end of the long, narrow, horizontal section.
11. **Antenna, Loop:** An antenna in which the wires form a closed circuit, part of which may be the ground.
12. **Antenna, Plain:** An approximately vertical single wire.
13. **Antenna, T:** A flat top antenna in which the horizontal section is long and narrow, the leading down wires being taken from the center.
14. **Antenna, Umbrella:** One whose conductors form the elements of a cone from the elevated apex of which the leading down wires are brought.
15. **Antenna Resistance:** An effective resistance which is numerically equal to the ratio of the power in the entire antenna circuit to the square of the R. M. S. current at a potential node (generally the ground).

    NOTE.—Antenna resistance includes radiation resistance; ground resistance; radio frequency ohmic resistance of antenna and loading coil and shortening condensers, equivalent resistance due to corona, eddy currents, and insulator leakage.
16. **Arc:** The passage of an electric current of relatively high density through a gas or vapor the conductivity of which is mainly due to the electron emission from the self-heated cathode. Under present practical conditions, the phenomena take place near atmospheric pressure.
17. **Arc Oscillator:** An arc used with an oscillating circuit for the conversion of direct to alternating or pulsating current. The oscillations generated are classified as follows:

    Class (1). Those in which the amplitude of the oscillation circuit current produced is less than the direct current through the arc.

    Class (2). Those in which the amplitude of the oscillation circuit current is at least equal to the direct current, but in which the direction of the current through the arc is never reversed.

26. Changer, Wave: A transmitting device for rapidly and positively changing the wave length.

27. Characteristic, Dynamic, of a Conductor: (For a given frequency and between given extremes of impressed E. M. F. and resultant current through the conductor): This is the relation given by the curve obtained when the impressed E. M. F.'s are plotted as ordinates against the resultant currents as abscissas, both E. M. F.'s and currents varying at the given frequency and between the given extremes.

28. Characteristic, Static, of a Conductor: This is the relation given by the curve plotted between the impressed electromotive force as ordinates and the resultant current through the conductor as abscissas, for substantially stationary conditions.

29. Coefficient, Attenuation, Radio: See Attenuation.

30. Coefficient of Amplification. See Amplification.

31. Coefficient of Coupling, Inductive: The ratio of the effective mutual inductance of two circuits to the square root of the product of the effective self-inductances of each of these circuits.

32. Coherer: A device sensitive to radio frequency energy, and characterized by (1) a normally high resistance to currents at low voltages, (2) a reduction in resistance on the application of an increasing electromotive force, this reduction persisting until eliminated by the application of a restoring or disturbing mechanical force, and (3) the substantial absence of thermoelectric or rectifying action.

33. Communication, Radio: The transmission of signals by means of electromagnetic waves originating in a constructed circuit.

34. Compass, Radio: A radio receiving device for determining the direction (or the direction and its opposite) in which maximum energy is received; or

A radio transmitting device for determining the direction (or the direction and its opposite) of maximum radiation.

35. Condenser, Air: A condenser having air as its dielectric.
36. Condenser, Compressed Gas: A condenser having compressed gas as its dielectric.
37. Conductor, Cage: See Cage Conductor.
38. Corona: See Brush or Corona Losses.
39. Counterpoise: A system of electrical conductors forming one portion of a radiating oscillator, the other portion of which is the antenna. In land stations, a counterpoise forms a capacitive connection to ground.
40. Coupler: An apparatus which is used to transfer radio frequency energy from one circuit to another by associating portions of these circuits.
41. Coupler, Capacitive: An apparatus which, by electric fields, joins portions of two radio frequency circuits; and which is used to transfer electrical energy between these circuits through the action of electric forces.
42. Coupler, Direct: A coupler which magnetically joins two circuits having a common conductive portion.
43. Coupler, Inductive: An apparatus which by magnetic forces joins portions of two radio frequency circuits and is used to transfer electrical energy between these circuits through the action of these magnetic forces.
44. Coupling: See Coefficient of Coupling (Inductive).
45. Current, Damped Alternating: An alternating current whose amplitude progressively diminishes. (Also called oscillating current.)
46. Current, Forced Alternating: A current, the frequency and damping of which are equal to the frequency and damping of the exciting electromotive force. See further Current, Free Alternating.

    NOTE.—During the initial stages of excitation, both free and forced currents co-exist.
47. Current, Free Alternating: The current following any transient eletromagnetic disturbance in a circuit having capacity, inductance, and *less* than the critical resistance. See further, Resistance, Critical.
48. Curve, Distribution, of a Radio Transmitting Station for a given distance: This is a polar curve the radii vectors of which are proportional to the field intensity

of the radiation at that distance in corresponding directions. See also Compass, Radio.

NOTE 1.—The distribution curve depends, in general, not only on the form of the antenna, but also on the nature of the ground surrounding the station.

NOTE 2.—The distribution curve generally varies with the distance from the station.

49. Curve, Resonance, Standard: A curve the ordinates of which are the ratios of the square of the current at any frequency to the square of the resonant current, and the abscissas are the ratios of the corresponding wave length to the resonant wave length; the abscissas and ordinates having the same scale.

50. Cyclogram: See Characteristic, Dynamic.

51. Cyclograph: An instrument for the production of cyclograms.

52. Decrement: See Decrement, Linear, and Logarithmic.

53. Decrement, Linear, of a Linearly Damped Alternating Current: This is the difference of successive current amplitudes in the same direction divided by the larger of these amplitudes.

NOTE.—Let I_n and I_{n+1} be successive current amplitudes in the same direction of a linearly damped alternating current.

Then, the linear decrement

$$b = \frac{I_n - I_{n+1}}{I_n}.$$

Also: $I_t = I_o\ (1 - bft)$,

Where $I_o =$ initial current amplitude,
$I_t =$ current amplitude at time t,
$f =$ frequency of alternating current.

54. Decrement, Logarithmic, of an exponentially damped alternating current: This is the logarithm of the ratio of successive current amplitudes in the same direction.

NOTE.—Logarithmic decrements are standard for a complete period or cycle.

Let I_n and I_{n+1} be successive current amplitudes in the same direction,

$d =$ logarithmic decrement,

then,

$$d = Log_{\epsilon} \frac{I_n}{}, \text{ where } \epsilon = 2.718 +.$$

NOTE 1.—For a given R. M. S. current at the base of the antenna, the field intensity at distant points is proportional to the form factor times the height of the antenna.

NOTE 2.—The effective height (height of center of capacity) is equal to the form factor times the actual height of the antenna.

NOTE 3.—The limiting values of the form factor for various types of antennas are as follows:

	Linear or Vertical Antenna.	Flat Top Umbrella Antenna.
Long Waves	Lower Limit, 1/2	Upper Limit, 1
Fundamental	Lower Limit, $2/\pi$	————————

NOTE 4.—The form factor varies in a given antenna at various wave lengths due to variation of the current distribution.

64. Frequencies, Audio (abbreviated a. f.): The frequencies corresponding to the normally audible vibrations. These are assumed to lie below 10,000 cycles per second.

65. Frequencies, Radio (abbreviated r. f.): The frequencies higher than those corresponding to the normally audible vibrations, which are generally taken as 10,000 cycles per second. See also Frequencies, Audio.

    NOTE.—It is not implied that radiation cannot be secured at lower frequencies, and the distinction from audio frequencies is merely one of definition based on convenience.

66. Frequency, Changer: See Changer, Frequency.

67. Frequency, Group: The number per second of periodic changes of amplitude or frequency of an alternating current.

    NOTE 1.—Where there is more than one periodically recurrent change of amplitude, or frequency, there is more than one group frequency present.

    NOTE 2.—The term "group frequency" replaces the term "spark frequency."

68. Frequency Transformer: See Changer, Frequency.

69. Fundamental of an Antenna: This is the lowest frequency of free oscillations of the unloaded antenna. (No series inductance or capacity.)
70. Fundamental Wave Length: The wave length corresponding to the lowest free period of any oscillator.
71. Gap, Micrometer: A device for protecting any apparatus from excessive potentials, and consisting of a short gap designed for fine adjustment.
72. Ground: A conductive connection to the earth.
73. Height, Effective, of an Antenna: See Factor, Form; Note 2.
74. Inductance, Effective, of an Antenna: See Capacity, Effective, of an Antenna.
75. Impulse Excitation: See Excitation, Impulse.
76. Interference, Wave (in Radio Communication): The reinforcement or neutralization of waves arriving at a receiving point along different paths from a given sending station (to be distinguished from ordinary or station interference, which is the simultaneous reception of signals from two or more stations).
77. Key: A switch arranged for rapidity of manual operation and normally used to form the code signals of a radiogram.
78. Key, Relay: See Relay Key.
79. Length, Wave: See Wave Length.
80. Losses, Brush or Corona: See Brush or Corona Losses.
81. Meter, Wave: See Wave Meter.
82. Oscillation (in Radio Work): See Current, Damped Alternating.
83. Oscillator, Arc: See Arc Oscillator.
84. Potentiometer: As commonly used for radio receiving apparatus, a device for securing a variable potential by utilizing the voltage drop across the variable portion of a current-carrying resistance.
85. Radiation, Sustained: See Waves, Sustained.
86. Radiogram: A telegram sent by radio.
87. To Radiograph (verb): To send a radiogram.
88. Radio Telephone: An apparatus for the transmission of speech by radio.

89. Radiophone (noun): A telephone message sent by radio.
90. To Radiophone (verb): To send a radiophone.
91. Rectifier, Electron: A device for rectifying an alternating current by utilizing the approximately unilateral conductivity between a hot cathode and relatively cold anode in so high a vacuum that a pure electron current flows between the electrodes.
92. Rectifier, Gas: An electron rectifier containing gas which modifies the internal action by the retardation of the electrons or the ionization of the gas atoms.
93. Relay, Electron: A device provided with the means for modifying the pure electron current flowing between a hot cathode and a relatively cold anode placed in as nearly as possible a perfect vacuum.

    These means may be, for example, an electric control of the pure electron current by variation of the potential of a grid interposed between the cathode and the anode.
94. Relay, Gas: An electron relay containing gas which modifies the internal action by the retardation of the electrons or the ionization of the gas atoms.
95. Relay Key: An electrically operated key. See further, Key.
96. Resistance, Antenna: See Antenna Resistance.
97. Resistance, Critical, of a Circuit: That resistance which determines the limiting condition at which the oscillatory discharge of a circuit passes into an aperiodic discharge.
98. Resistance, Effective, of a Spark: The ratio of the power dissipated by the spark to the mean square current.
99. Resistance, Radiation: This is the ratio of the total energy radiated (per second) by the antenna to the square of the R. M. S. current at a potential node (generally the ground connection). See further, Antenna Resistance.
100. Resistance, Radio Frequency: This is the ratio of the heat produced per second in watts to the square of the R. M. S. current (r. f.) in amperes in a conductor.

111. Train, Wave: The waves emitted which correspond to a group of oscillations in the transmitter. See also, Frequency, Group.
112. Transformer: In present radio practice the term should be restricted to audio frequency transformers. See Frequency, Audio.
113. Transmission, Diplex: See Diplex Transmission.
114. Tuning: The process of securing the maximum indication by adjusting the time period of a driven element. See Resonance.
115. Tuning, Sharpness of: See Sharpness of Tuning.
116. Vacuum Tube, Three Electrode: As examples see Relays, Electron and Gas.
117. Vacuum Tube, Two Electrode: As examples see Rectifiers, Electron and Gas.
118. Waves, Electromagnetic: A periodic electromagnetic disturbance progressive through space.
119. Wave Length (of an Electromagnetic Wave): The distance in meters between two consecutive maxima, of the same sign, of the electric and magnetic forces.
120. Wave Length, Fundamental: See Fundamental Wave Length.
121. Wave Length, Natural: In a loaded antenna (that is, with series inductance or capacity) the natural wave length corresponds to the lowest free oscillation.
122. Wave Changer: See Changer, Wave.
123. Wave Meter: A radio frequency measuring instrument calibrated to read wave lengths.
124. Waves, Sustained: Waves radiated from a conductor in which an alternating current flows.
125. Wave Train: See Train, Wave.

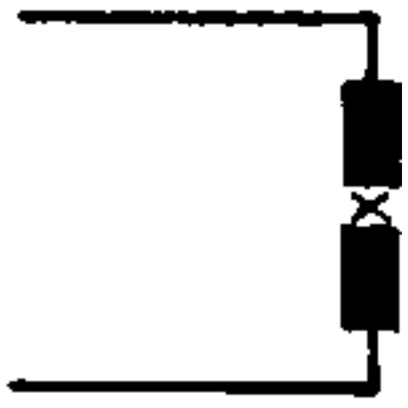
APPENDIX B.

STANDARD GRAPHICAL SYMBOLS.

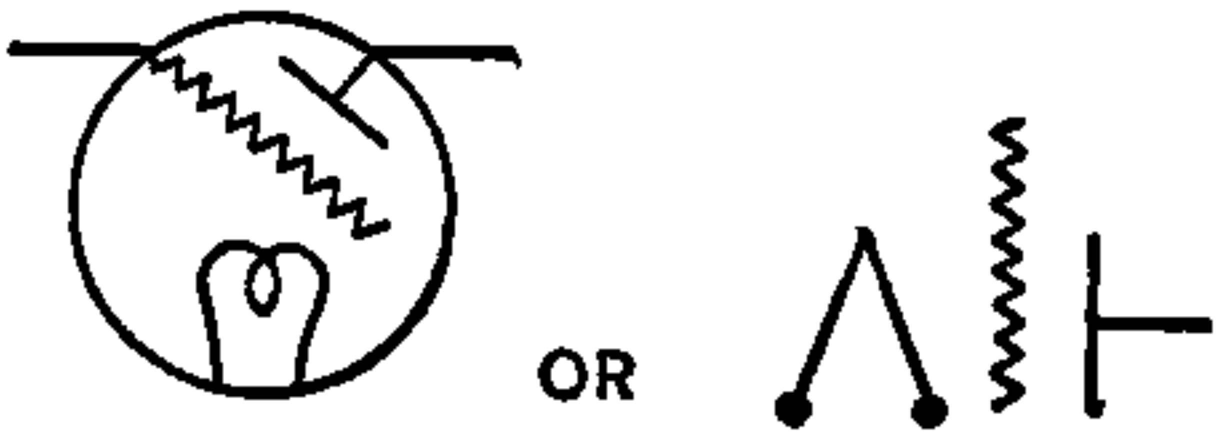
Ammeter ....

Antenna ....

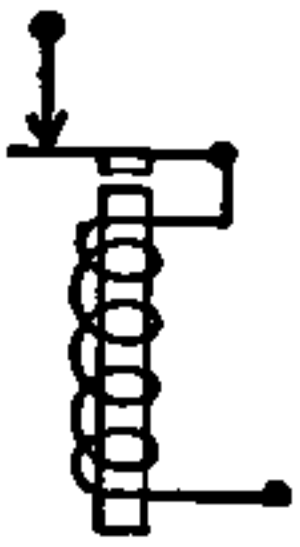
Arc ....



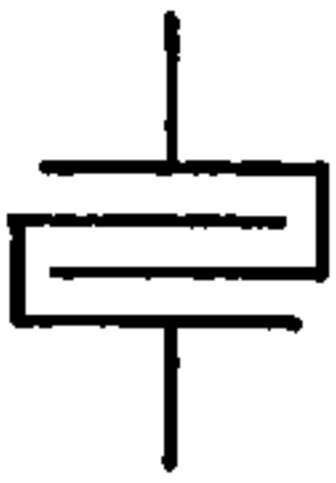
Audion bulb (three electrode vacuum tube) ....



Buzzer ....

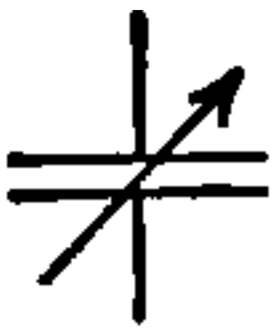


Condenser, Audio frequency ....

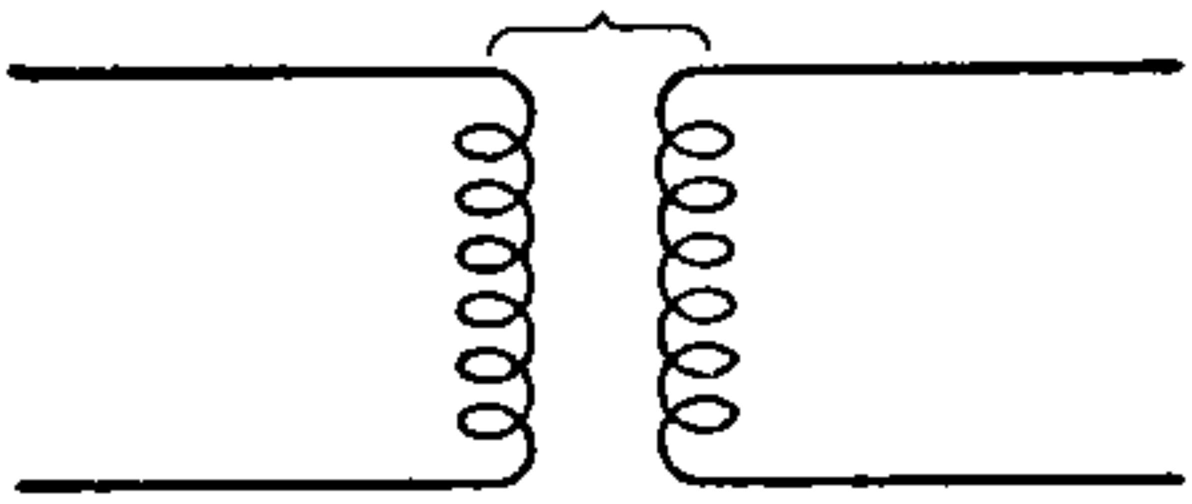


Condenser, Radio frequency ....

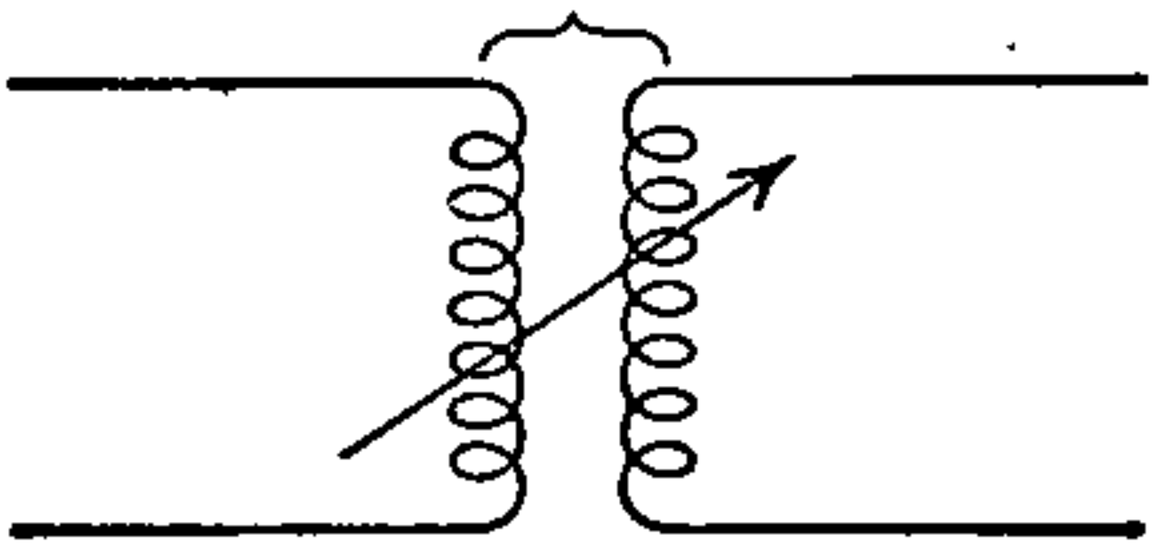
Condenser, Variable ....



Coupler, Inductive ....



Coupler, Inductive, Variable......



Detector ....

Gap, Non-synchronous ....

Gap, Quenching ....

Gap, Spark ....

Gap, Synchronous ....

Ground ....

Voltmeter .... 

Wattmeter .... 

Wave Meter .... 

APPENDIX C.

INTERNATIONAL MORSE CODE AND CONVENTIONAL SIGNALS.

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	——··

1	·————
2	··———
3	···——
4	····—
5	·····
6	—····
7	——···
8	———··
9	————·

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	

APPENDIX D.

EXTRACT FROM LAWS GOVERNING RADIO COMMUNICATION

[PUBLIC—No. 264.]

[S. 6412.]

An Act to regulate radio communication.

Be it enacted by the Senate and House of Representatives of the United States of America in Congress assembled, That a person, company or corporation within the jurisdiction of the United States shall not use or operate any apparatus for radio communication as a means of commercial intercourse among the several states, or with foreign nations, or upon any vessel of the United States engaged in interstate or foreign commerce, or for the transmission of radiograms or signals the effect of which extends beyond the jurisdiction of the State or Territory in which the same are made, or where interference would be caused thereby with the receipt of messages or signals from beyond the jurisdiction of the said State or Territory, except under and in accordance with a license, revocable for cause, in that behalf granted by the Secretary of Commerce and Labor upon application therefor; but nothing in this Act shall be construed to apply to the transmission and exchange of radiograms or signals between points situated in the same State; *Provided,* That the effect thereof shall not extend beyond the jurisdiction of the said State or interfere with the reception of radiograms or signals from beyond said jurisdiction; and a license shall not be required for the transmission or exchange of radiograms or signals by or on behalf of the Government of the United States, but every Government station on land or sea shall have special call letters designated and published in the list of radio stations of the United States by the Department of Commerce and Labor. Any person, company, or corporation that shall use or operate any apparatus for radio communication in violation of this section, or knowingly aid or abet another

who in the operation of any radio apparatus shall fail to observe and obey regulations contained in or made pursuant to this Act or subsequent acts or treaties of the United States, or any one of them, or who shall fail to enforce obedience thereto by an unlicensed person while serving under his supervision, in addition to the punishments and penalties herein prescribed, may suffer the suspension of the said license for a period to be fixed by the Secretary of Commerce and Labor not exceeding one year. It shall be 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 apparatus, and any person violating this provision shall be guilty of a misdemeanor, and on conviction thereof shall be punished by a fine of not more than one hundred dollars or imprisonment for not more than two months, or both, in the discretion of the court for each and every such offense: *Provided,* That in case of emergency the Secretary of Commerce and Labor may authorize a collector of customs to issue a temporary permit, in lieu of a license, to the operator on a vessel subject to the radio ship Act of June twenty-fourth, nineteen hundred and ten.

4. That for the purpose of preventing or minimizing interference with communication between stations in which such apparatus is operated, to facilitate radio communication, and to further the prompt receipt of distress signals, said private and commercial stations shall be subject to the regulations of this section. These regulations shall be enforced by the Secretary of Commerce and Labor through the collectors of customs and other officers of the Government as other regulations herein provide for.

The Secretary of Commerce and Labor may, in his discretion, waive the provisions of any or all of these regulations when no interference of the character above mentioned can ensue.

The Secretary of Commerce and Labor may grant special temporary licenses to stations actually engaged in conducting experiments for the development of the science of radio communication, or the apparatus pertaining thereto, to carry on special tests, using any amount of power or any wave lengths, at such hours and under such conditions as will insure the least interference with the sending or receipt of commercial or Government radiograms, of distress signals and radiograms, or with the work of other stations.

In these regulations the naval and military stations shall be understood to be stations on land.

REGULATIONS.

NORMAL WAVE LENGTH.

First. Every station shall be required to designate a certain definite wave length as the normal sending and receiving wave length of the station. This wave length shall not exceed six hundred meters or it shall exceed one thousand six hundred meters. Every coastal station open to general public service shall at all times be ready to receive messages of such wave lengths as are required by the Berlin convention. Every ship station, except as hereinafter provided, and every coast station open to general public service shall be prepared to use two sending wave lengths, one of three hundred meters and one of six hundred meters, as required by the International convention in force: *Provided*, That the Secretary of Commerce and Labor may, in his discretion, change the limit of wave length reservation made by regulations first and second to accord with any international agreement to which the United States is a party.

OTHER WAVE LENGTHS.

Second. In addition to the normal sending wave length all stations, except as provided hereinafter in these regulations, may use other sending wave lengths: *Provided*, That they do not exceed six hundred meters or that they do exceed one thousand six hundred meters; *Provided further*, That the character of the waves emitted conforms to the requirements of regulations third and fourth following.

USE OF A "PURE WAVE."

Third. At all stations if the sending apparatus, to be referred to hereinafter as the "transmitter," is of such a character that the energy is radiated in two or more wave lengths, more or less sharply defined, as indicated by a sensitive wave meter, the energy in no one of the lesser waves shall exceed ten per centum of that in the greatest.

USE OF A "SHARP WAVE."

Fourth. At all stations the logarithmic decrement per complete oscillation in the wave trains emitted by the transmitter shall not exceed two-tenths except when sending distress signals or signals and messages relating thereto.

USE OF "STANDARD DISTRESS WAVE."

Fifth. Every station on shipboard shall be prepared to send distress calls on the normal wave length designated by the international convention in force, except on vessels of small tonnage unable to have plants insuring that wave length.

SIGNAL OF DISTRESS.

Sixth. The distress call used shall be the international signal of distress ● ● ● ▬ ▬ ▬ ● ● ●

USE OF "BROAD INTERFERING WAVE" FOR DISTRESS SIGNALS.

Seventh. When sending distress signals, the transmitter of a station on shipboard may be tuned in such a manner as to create a maximum of interference with a maximum of radiation.

DISTANCE REQUIREMENT FOR DISTRESS SIGNALS.

Eighth. Every station on shipboard, wherever practicable, shall be prepared to send distress signals of the character specified in regulations fifth and sixth with sufficient power to enable them to be received by day over sea a distance of one hundred nautical miles by a shipboard station equipped with apparatus for both sending and receiving equal in all essential particulars to that of the station first mentioned.

concerning wave lengths and character of signals emitted, such private or commercial shore stations as do interfere with the reception of signals by the naval and military stations concerned shall not use their transmitters during the first fifteen minutes of each hour, local standard time. The Secretary of Commerce and Labor may, on the recommendation of the department concerned, designate the station or stations which may be required to observe this division of time.

GOVERNMENT STATIONS TO OBSERVE DIVISION OF TIME.

Thirteenth. The naval or military stations for which the above-mentioned division of time may be established shall transmit signals or radiograms only during the first fifteen minutes of each hour, local standard time, except in case of signals or radiograms relating to vessels in distress, as hereinbefore provided.

USE OF UNNECESSARY POWER.

Fourteenth. In all circumstances, except in case of signals or radiograms relating to vessels in distress, all stations shall use the minimum amount of energy necessary to carry out any communication desired.

GENERAL RESTRICTIONS ON PRIVATE STATIONS.

Fifteenth. No private or commercial station not engaged in the transaction of bona fide commercial business by radio communication or in experimentation in connection with the development and manufacture of radio apparatus for commercial purposes shall use a transmitting wave length exceeding two hundred meters, or a transformer input exceeding one kilowatt, except by special authority of the Secretary of Commerce and Labor contained in the license of the station: *Provided*, That the owner or operator of a station of the character mentioned in this regulation shall not be liable for a violation of the requirements of the third or fourth regulations to the penalties of one hundred dollars or twenty-five dollars, respectively, provided in this section unless the person maintaining or operating such station shall have been notified in writing that the said transmitter has been found, upon tests conducted by the Government, to be so adjusted as to violate the said third and fourth regulations, and opportunity has been given to said owner or operator to adjust said transmitter in conformity with said regulations.

SPECIAL RESTRICTIONS IN THE VICINITIES OF GOVERNMENT STATIONS.

Sixteenth. No station of the character mentioned in regulation fifteenth situated within five nautical miles of a naval or military station shall use a transmitting wave length exceeding two hundred meters or a transformer input exceeding one-half kilowatt.

SHIP STATIONS TO COMMUNICATE WITH NEAREST SHORE STATIONS.

Seventeenth. In general, the shipboard stations shall transmit their radiograms to the nearest shore station. A sender on board a vessel shall, however, have the right to designate the shore station through which he desires to have his radiograms transmitted. If this cannot be done, the wishes of the sender are to be complied with only if the transmission can be effected without interfering with the service of other stations.

LIMITATIONS FOR FUTURE INSTALLATIONS IN VICINITIES OF GOVERNMENT STATIONS.

Eighteenth. No station on shore not in actual operation at the date of the passage of this Act shall be licensed for the transaction of commercial business by radio communication within fifteen nautical miles of the following naval or military stations, to wit: Arlington, Virginia; Key West, Florida; San Juan, Porto Rico; North Head and Tatoosh Island, Washington; San Diego, California; and those established or which may be established in Alaska and in the Canal Zone; and the head of the department having control of such Government stations shall, so far as is consistent with the transaction of governmental business, arrange for the transmision and receipt of commercial radiograms under the provisions of the Berlin convention of nineteen hundred and six and future international conventions or treaties to which the United States may be a party, at each of the stations above referred to, and shall fix the rates therefor, subject to control of such rates by Congress. At such stations and wherever and whenever shore stations open for general public business between the coast and vessels at sea under the provisions of the Berlin convention of nineteen hundred and six and future international conventions and treaties to which the United States may be a party shall not be so established as to insure a constant service day and night without interruption, and in all localities wherever or whenever such service shall not be maintained by a commercial shore station within one hundred nautical miles of a naval radio station, the Secretary of the Navy shall, so far as is consistent with the transaction of governmental business, open naval radio stations to the general public business described above, and shall fix rates for such service, subject to control of such rates by Congress. The receipts from such radiograms shall be covered into the Treasury as miscellaneous receipts.

SECRECY OF MESSAGES.

Nineteenth. No person or persons engaged in or having knowledge of the operation of any station or stations, shall divulge or publish the contents of any messages transmitted or received by such station, except to the person or persons to whom the same may be directed, or their authorized agent, or to another station employed to forward such message to its destination, unless legally required so to do by the court of competent jurisdiction or other competent authority. Any person guilty of divulging or publishing any message, except as herein provided, shall, on conviction thereof, be punishable by a fine of not more than two hundred and fifty dollars or imprisonment for a period of not exceeding three months, or both fine and imprisonment, in the discretion of the court.

PENALTIES.

For violation of any of these regulations, subject to which a license under sections one and two of this Act may be issued,

years, or both, in the discretion of the court, for each and every such offense.

SEC. 8. That a person, company, or corporation shall not use or operate any apparatus for radio communication on a foreign ship in territorial waters of the United States otherwise than in accordance with the provisions of sections four and seven of this Act and so much of section five as imposes a penalty for interference. Save as aforesaid, nothing in this Act shall apply to apparatus for radio communication on any foreign ship.

SEC. 9. That the trial of any offense under this Act shall be in the district in which it is committed, or if the offense is committed upon the high seas or out of the jurisdiction of any particular State or district the trial shall be in the district where the offender may be found or into which he shall be first brought.

SEC. 10. That this Act shall not apply to the Philippine Islands.

SEC. 11. That this Act shall take effect and be in force on and after four months from its passage.

Approved, August 13, 1912.

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