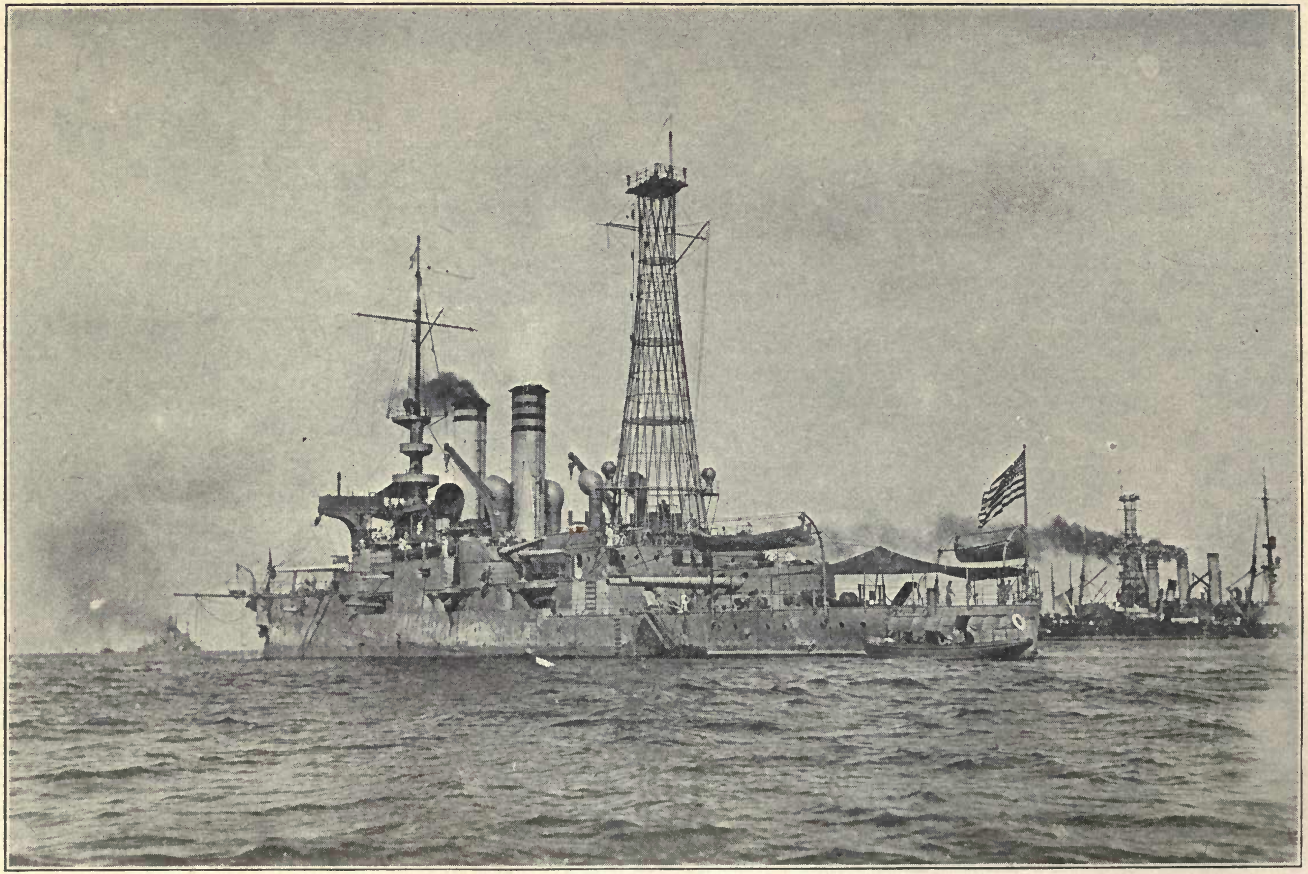
WIRELESS TELEGRAPHY AND WIRELESS TELEPHONY

ASHLEY—HAYWARD

AMERICAN SCHOOL of CORRESPONDENCE

CHICAGO ILLINOIS



BATTLESHIP SUPPLIED WITH WIRELESS TELEGRAPH EQUIPMENT

The New- and Old-Style Masts or Aërials are shown in Contrast—the New at the Right, and the Old at the Left.

WIRELESS TELEGRAPHY
AND
WIRELESS TELEPHONY

AN UNDERSTANDABLE PRESENTATION OF THE SCIENCE OF WIRELESS TRANSMISSION OF INTELLIGENCE

By

CHARLES G. ASHLEY
ELECTRICAL ENGINEER

And

CHARLES B. HAYWARD
CONSULTING ENGINEER; MEMBER, SOCIETY OF AUTOMOBILE ENGINEERS

ILLUSTRATED

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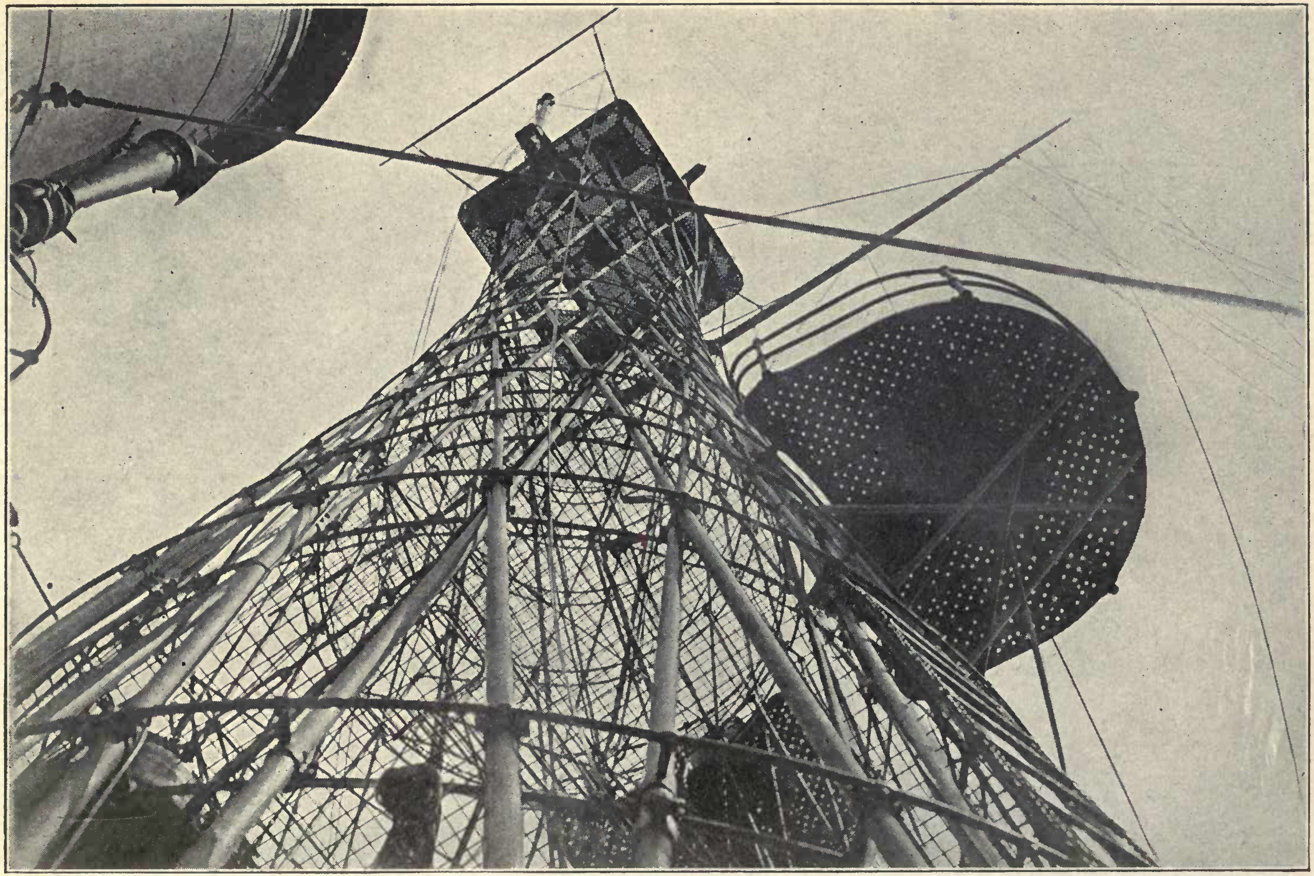


NEW STYLE OF BATTLESHIP MAST OR AËRIAL

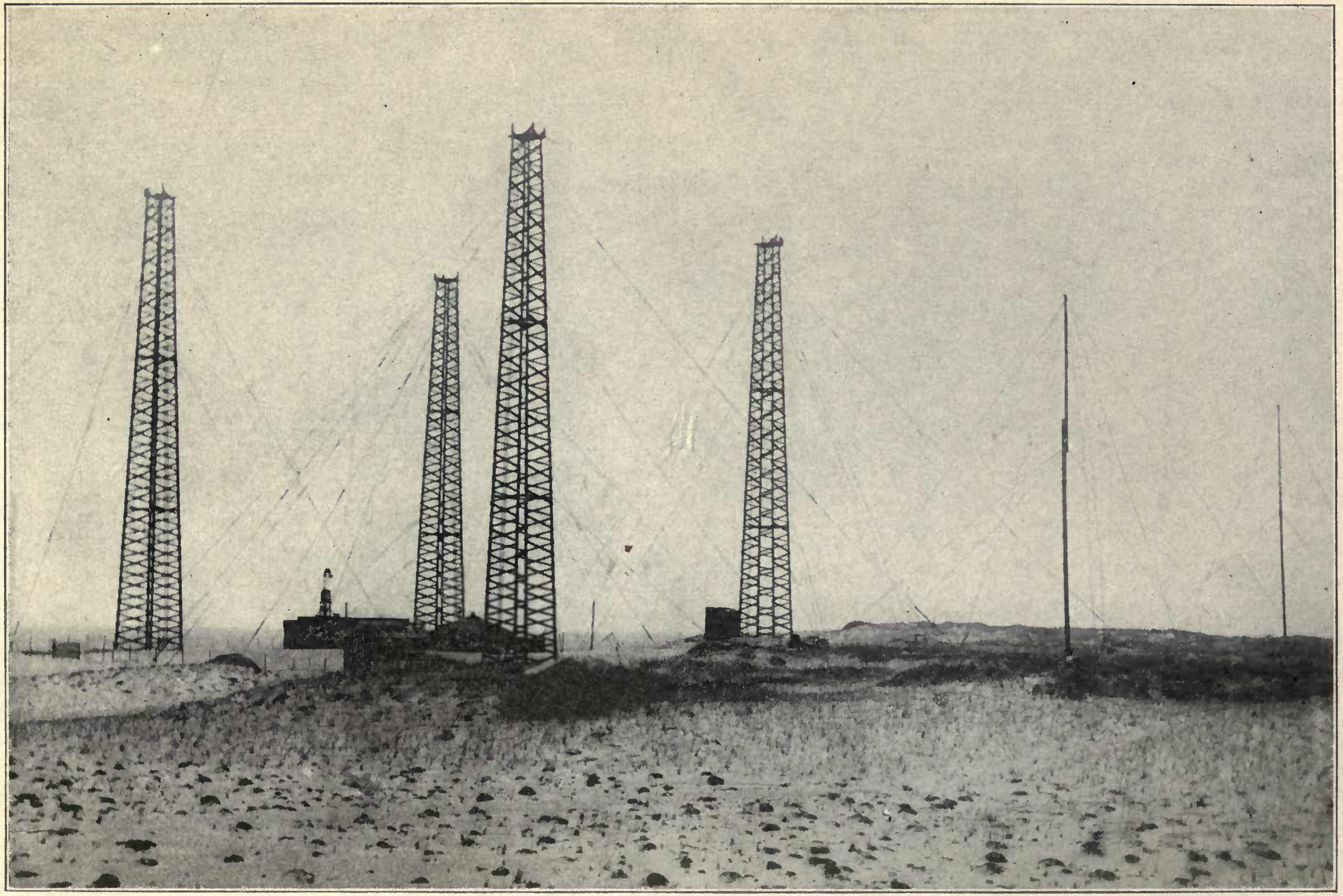
Showing Construction of the Type of Tower which now carries the Wireless. Photograph was taken from Base of Mast.

INTRODUCTION

WIRELESS TELEGRAPHY was the subject of earnest experimentation as early as 1838, but as far as the public mind is concerned the science began when Marconi sent his first message across the Atlantic from Cornwall to Nova Scotia in 1902. This wonderful accomplishment, like the startling application of the X-rays by Roentgen, had so much of the spectacular element in it, that wireless telegraphy and Marconi became famous at once. The notable rescues of the passengers of the Republic and the Titanic by the aid of wireless messages have only heightened this interest, and it was to satisfy the demand for a practical and understandable presentation of the subject that this little book has been published.

The development of the wireless telegraph is carried out logically from the early forms to the latest adaptations of the most important systems. The discussion also includes its application to the aeroplane and dirigible.

Wireless Telephony, seemingly even more mysterious than telegraphy, is being rapidly developed, the entire absence of the disturbing noises, so characteristic of the land telephone, making this mechanism especially attractive. Its use between ship and shore for considerable distances has long since passed the experimental stage.



MARCONI WIRELESS TELEGRAPH STATION AT SOUTH WELLFLEET, MASSACHUSETTS
Towers 215 Feet High.

WIRELESS TELEGRAPHY

INTRODUCTION

As a first step into the subject of wireless telegraphy it may be well to consider the meaning of the term. Wire telegraphy is characterized by the employment of extended metallic lines or conductors over which it is possible to transmit intelligence electrically by means of an arbitrary code of signals. Wireless telegraphy is characterized by the absence of such lines in the accomplishment of the same end. Many have confounded wireless telegraphy with the system invented by Marconi; but the latter is only one form out of many: the term was used to describe other systems years before Marconi's spectacular success added it to the popular vocabulary. As a matter of fact any system of telegraphy which successfully substitutes some other medium for the connecting wires, may properly be called "wireless." The systems of wireless telegraphy so far proposed may be classified as follows: Conduction Systems; Induction Systems; and Radiation Systems.

The history of the subject follows very closely the above sequence in point of time. First came the conduction systems—the attempt to substitute the earth and bodies of water in place of the connecting lines. Then came the induction systems, taking advantage of those peculiar electrical phenomena known as electrostatic and electrodynamic induction: here the substituted medium was the ether—that invisible, intangible substance which is supposed to fill all space. Last came the radiation systems, which also make use of the ether, but in a different way, namely, by disturbing it in such a manner as to produce far-reaching waves which can be detected at distant points. It is the last type, known as *radiotelegraphy*, which is today paramount, having superseded the other two by reason of its superior utility and effectiveness. Its startling development during the past ten years may justly be called a "fairy tale of science." The earlier systems are important, however, as they mark the birth and the development of an idea.

CHAPTER I

EARLY FORMS

Conduction Systems. The essential feature of all conduction systems is that *some other form of material conductor is substituted for that of wires.* These substitutes have been in all cases either earth or bodies of water, because they are the only natural conductors which are sufficiently common and extensive to be utilized.

Work of Steinheil. Today it seems glaringly obvious that the earth may be used as a conductor, but in 1838 when Steinheil, a Bavarian, accidentally discovered this fact, it created quite a sensation. He had been experimenting with the steel rails of a railroad trying to utilize them as substitutes for the wires of a telegraph circuit, but was unable to obtain sufficient insulation. He was surprised to discover, however, what a high degree of conductivity the earth possessed, and was led to conceive that he might employ it instead of the return wire hitherto used. He made the experiment, and with complete success, thus introducing into telegraphy one of its most important features—the earth circuit. Expanding the idea, Steinheil wondered if it were not possible to telegraph through the earth without using metallic conductors at all. This experiment, which was successful over very short distances, is said to have been the first attempt to telegraph without wires. Steinheil, however, being unable to signal farther than 50 feet, gave up this method, convinced that it was inexpedient for telegraphy.

Morse System. S. F. B. Morse, who is famed as the inventor of wire telegraphy and of the code which still bears his name, was, by a strange coincidence, also one of the pioneers of telegraphy without wires. In 1844 he addressed a letter to Congress in which he related his experiments in this field and gave an interesting account of his inception of the idea. A portion of the document, considerably abridged, is as follows:

> In the autumn of 1842, at the request of the American Institute, I undertook to give to the public in New York a demonstration of the practicability

of my telegraph, by connecting Governor's Island with Castle Garden, a distance of a mile; and for this purpose I laid my wires properly insulated beneath the water. I had scarcely begun to operate, and had received but two or three characters, when my intentions were frustrated by the accidental destruction of a part of my conductors by a vessel which drew them up on her anchor and cut them off. In the moments of mortification I immediately devised a plan for avoiding such accidents in the future, by so arranging my wires along the banks of the river as to cause the water itself to conduct the electricity across. The experiment, however, was deferred until I arrived in Washington; and on Dec. 16, 1842, I tested my arrangement across the canal, and with success. The simple fact was then ascertained that electricity could be made to cross a river without other conductors than the water itself; but it was not until the last autumn that I had the leisure to make a series of experiments to ascertain the law of its passage. The diagram, Fig. 1, will serve to explain the experiment.

A, *B*, *C*, *D*, are the banks of the river; *N P* is the battery; *G* is the galvanometer; *W W* are the wires along the banks, connected with copper plates *f*, *g*, *h*, *i*, which are placed in the water. When this arrangement is complete, the electricity, generated by the battery, passes from the positive pole *P* to the plate *h*, across the river through the water to plate *i*, and thence around the coil of the galvanometer to plate *f*, across the river again to plate *g*, and thence to the other pole of the battery *N*.

Morse here appends a table of his results, "showing," as he says, "that electricity crosses the river, and in quantities in propor-

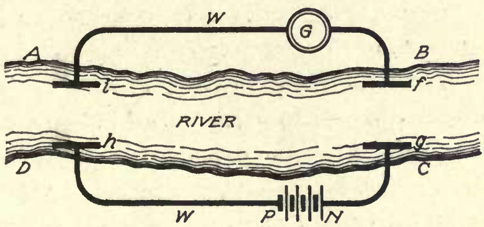


Fig. 1. Experiment of Morse

tion to the size of the plates in the water. The distance of the plates on the same side of the river from each other also affects the result." This distance he states elsewhere should be three times greater than that from shore to shore across the stream.

Morse's plan contains in a simple form all the essential features of all later endeavors to telegraph by the conduction method whether utilizing water or earth as the medium. Lindsay, Highton, Dering, Stevenson, Preece, Smith, and others subsequently worked out more elaborate and extensive methods all resting primarily on the same principle as above. None of them succeeded in signaling much farther than three miles. These early results indicate the inherent limitations which have ever remained as insurmountable difficulties to the commercial adoption of this form of wireless telegraphy.

Induction Systems. Induction is an electrical influence exerted by a charged body or by a magnetic field on neighboring bodies without apparent communication. The laws of it are well known to electrical science through the classic researches of Faraday. Induction comprehends two classes of phenomena known, respectively, as *electrostatic induction* and *electrodynamic induction:* the former is that property of the electrostatic field which produces an electric charge in a conductor when brought into the said field; while the latter is that property of the magnetic field by virtue of which electromotive forces are created in conductors by a relative movement between said field and such conductors. Without attempting to go further into the matter here, it suffices to say that investigators were not slow in appreciating that induction offered a means of communication which could be classified as "wireless."

Dolbear System. What is now generally considered to be an extreme case of electrostatic induction is the remarkable system of wireless communication invented by Prof. Dolbear of Tufts College, Boston, in 1882. This system is of especial historical interest owing to its startling resemblance to the system devised later by Marconi. Dolbear's invention may be best explained by referring to Fig. 2. The left side represents the transmitting circuit and the right, the receiving circuit. *B* is a battery connected through a carbon transmitter to the primary winding of an induction coil, the secondary terminals, *A* and *C*, of which are connected, respectively, with an elevated wire and the ground. The receiving end consists essentially of a similar elevated wire *A* connected to one terminal of a telephone receiver, the companion terminal of which is connected directly with the earth. The higher these wires are raised, the farther signals can be transmitted, so that Dolbear was prompted to attach them to kites. This is a curious anticipation of Marconi's antennae. Dolbear later made many modifications in his apparatus in an endeavor to reach greater distances by employing condensers raised to a considerable height and charged by batteries; but the system remained in all important respects the same as shown.

The apparatus works as follows: The diaphragm of the telephone transmitter is set into vibration by talking or whistling, thereby producing variations of resistance in the powdered carbon; this constantly varies the amount of current which flows into the induction coil; and consequently the wire A is charged to potentials which are constantly fluctuating in value, the degree of fluctuation depending on the degree of variation of resistance in the transmitter. The wire A' at the receiving station follows by electrostatic induction all the fluctuations of A; and with every change of potential, currents flow between A' and the ground through the telephone receiver R.

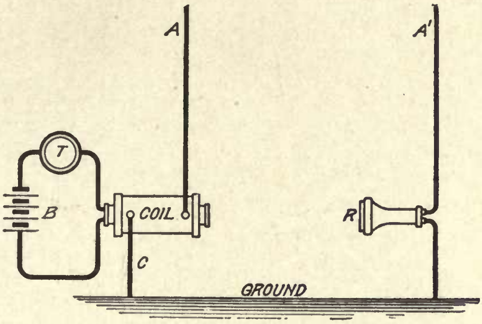


Fig. 2. Diagram of the Dolbear System

The latter consequently repeats all the vibrations set up in the transmitter, and the corresponding sound is reproduced. This particular method of operation is telephonic; but it will be seen that the same, or rather better, results could be obtained by a Morse key and telephonic receiver.

Edison System. Edison patented, in 1885, a system of inductive telegraphy, the particular purpose of which was to effect communication with moving trains. The ordinary telegraph wire, which commonly runs parallel to a railroad track, was utilized for one of the inductive circuits, and the train was equipped with another. The latter consisted mainly of a large, metallic condensing plate set on the roof of the car and connected to the secondary terminals of an induction coil, to the primary terminals of which were connected suitable transmitting and receiving instruments. When the Morse key in the primary circuit was depressed, the large condensing plate received static impulses and these acted inductively on the neighboring telegraph wire, which thereby received and conducted equivalent impulses to the nearest station equipped with proper receiving instruments. Or in case another train equipped as above were traveling on the same track, it could pick off the message inductively from the telegraph wire. In this manner two moving trains might communicate. This ingenious system was put into practical operation on the Lehigh Valley Railroad in 1887, and worked with undoubted success; but from a business point of view it proved a failure as there was no public demand for such service.

Work of Preece. One of England's most successful investigators in the field of wireless telegraphy was Sir Wm. Preece, chief electrician of the British Postal Telegraphs. He performed numerous experiments which added greatly to the theory of all forms of inductive and conductive communication. One of his most successful achievements was to effect inductive communication between Gloucester and Bristol on the banks of the Severn, a distance of nearly five miles. Parallel to the two shores were stretched on telegraph poles two closed wire circuits extending about 14 miles each. One of these circuits was traversed by a rapidly interrupted current of about .5 amperes. A telephone receiver inserted in the companion circuit responded to the frequency of the current in the other by a continuous sound upon pressure of the transmitting key. This form of communication was at one time resorted to quite frequently between stations separated by bodies of water under which it was inexpedient to lay cables.

Such systems may be characterized as "wireless" only through courtesy, since they demand an amount of wire which far exceeds that required by any ordinary wire system covering the same distance; they come under the classification of wireless telegraphy, however, since the wire conductors are not continuous, some other medium being interposed.

In the year 1885, Preece carried on very extensive investigations upon the possibilities of induction as an agency of communication, and summarized his observations as follows:

> Although communication across space has thus been proved to be practical in certain conditions, those conditions do not exist in the cases of isolated lighthouses and light-ships, cases which it was specially desired to provide for. The length of the secondary must be considerable, and, for good effects,

at least equal to the distance separating the two conductors. Moreover, the apparatus to be used on each circuit is cumbrous and costly, and it may be more economical to lay a submarine cable.

These conclusions are equally true to the present day. The necessity for a large base area remains the prohibiting factor in the adoption of electromagnetic induction systems. For a very painstaking review of the various early attempts at this form of telegraphy, the reader is referred to J. J. Fahie's excellent book, "A History of Wireless Telegraphy."

Summary. The conduction and induction methods of wireless telegraphy, although of great historical and experimental value, are of little practical value. Today their use is most exceptional because their utility is too limited—the supreme test for any system of wireless telegraphy being the test of long distance. They have been superseded by a type of wireless telegraphy which can achieve communication across an ocean if necessary—a type which is the product of an entirely different principle, the principle of electromagnetic radiation. In order to differentiate it from other forms of wireless telegraphy, this system is best denominated by the term *radiotelegraphy*, and a discussion of its underlying theory, its operation, and the arrangement of necessary apparatus will be found in the following chapters.

CHAPTER II

ELECTRIC WAVES

Electromagnetic Theory of Light. In order to understand radiotelegraphy with any degree of completeness one must first have a comprehension of the theory of electric waves, including the electromagnetic theory of light. This theory, with its verification, was one of the most notable scientific achievements of the last century. However, let it be remembered that, having adopted a working hypothesis—the most tenable one at present—to account for the ether and the *modus operandi* of ether waves, it is necessary as well as convenient to use the terms and implications of such hypothesis positively and with consistency throughout. Such unqualified use of terms might give foundation to the charge of scientific dogmatism were it not remembered at all times that we are dealing with a theory, generally accepted, it is true, but subject to the trials and mutations which such theories have undergone in the past. The reasonings from the working hypothesis are valid for the purpose for which they are here employed; but no true scientist will at present claim that such reasonings should or can be extended to the higher realm of absolute truth. In the words of H. Poincaré, "It matters little whether the ether really exists; that is the affair of metaphysicians. The essential thing for us is that everything happens as if it existed, and that this hypothesis is convenient for the explanation of the phenomena."

The electromagnetic theory of light was first completely stated in 1864, when James Clerk Maxwell, an English mathematician, sent to the Royal Society a paper entitled "A Dynamical Theory of the Ether," wherein he demonstrated his conviction that light and electricity were phenomena of a kindred nature—in fact, that light was an electrical manifestation. Maxwell's paper came as the result of a long series of investigations which had been carried on in two different departments of Physics—Optics and Electricity. These investigations had led on the one hand to a theory of a light-bearing medium called the *luminiferous ether*, and on the other hand to a theory of an electromagnetic medium also called the *ether*. Maxwell made a synthesis of these two theories, demonstrating that the hypothetical medium was the same in both cases, and that it was governed by electromagnetic laws.

The Luminiferous Ether. When we observe that light takes time to travel from place to place, and that it comes to the earth from the sun and stars across vast spaces which are not, so far as we know, filled with tangible matter, the inference necessarily follows that light is either a substance transmitted bodily, like a stone hurled from one place to another, or a physical state propagated through a stationary medium in the form of waves. Various investigators have demonstrated that light is a phenomenon of the latter description—that it is a physical state, or change of state, propagated through a stationary medium in the form of undulatory waves, the velocity of the waves being approximately 186,500 miles per second. Investigators agreed to call this medium the ether, prefixing the adjective "luminiferous" which means "light-bearing." They had neither seen nor felt the ether—directly or indirectly—but they reasoned that the ether must exist, else the facts of Optics were inexplicable. They held that it must be some peculiar form of matter which interpenetrated all ordinary forms of matter, and must also be distributed everywhere throughout the space of the universe. Up to Maxwell's time, however, they knew almost nothing of the ether itself, except that it behaved like an incompressible liquid, extremely tenuous but exceedingly rigid, and that the waves were of the kind classed as "transverse."

The Electromagnetic Medium. In the department of Electricity a theory of an electromagnetic medium had also grown up, following on the researches of Ampère, Henry, and Faraday. The fact that electrified bodies or magnets attracted or repelled each other at a distance, and that electric currents could create other currents in wires at a distance, and that these actions were not fundamentally dependent upon the presence of any material substance in the space between, led these investigators to conceive that there must be an electromagnetic medium by means of which such actions were transmitted across apparently empty spaces. They named this medium the ether, the same name adopted by investigators in the department of Optics; but it was a long time before anyone even surmised that there was any kinship between the luminiferous medium and the electromagnetic medium.

Work of Faraday. The first man to hint at the above possibility was Faraday, who, in 1845, discovered the singular fact that the magnet exercises a peculiar action on light, the plane of polarization of a polarized beam being rotated when the beam passes along a magnetic field. This seemed to show that there was some relation between electricity and light. Faraday persevered in these experiments. He wrote a paper entitled "Thoughts on Ray Vibrations" wherein he expressed his belief that radiation of all kinds—light, heat, etc.—were due to a high species of vibration of the lines of force in the magnetic field. Faraday's speculations may be said to have been the inception of the electromagnetic theory of light; he is indeed entitled to a large share of the credit; but his were only speculations, unformulated and incomplete, and it remained for another man to elaborate them into a complete theory mathematically demonstrable.

Work of Maxwell. When Maxwell, in 1864, sent his paper on "A Dynamical Theory of the Electromagnetic Field" to the Royal Society, one of his first steps was to acknowledge his debt to Faraday. He writes, "The conception of the propagation of transverse magnetic disturbances to the exclusion of normal ones is distinctly set forth by Prof. Faraday in his 'Thoughts on Ray Vibrations.' The electromagnetic theory of light as proposed by him is the same in substance as that which I have begun to develop in this paper, except that in 1846 there was no data to calculate the velocity of propagation." Maxwell then proceeds to give new equations to express the relations between the electric and the magnetic displacements in the medium and the forces which result from them. He shows that when magnetic methods of measurement are used, the unit of electricity arrived at has a certain value; but when purely electrical methods are used the unit proves to have a different value. The relation between these two units is dependent on the "electric elasticity" of the medium, and when measured proves to be a certain velocity—186,500 miles per second. This velocity, in other words, is that velocity with which an electromagnetic disturbance is propagated through the electromagnetic field. It will be remembered that the velocity of light was already known to be about 186,000 miles per second. Maxwell comments on the startling similarity as follows: "This velocity is so nearly that of light, that it seems we have strong reason to conclude that light itself (including radiant heat, and other radiations, if any) is an electromagnetic disturbance in the form of waves propagated through the electromagnetic field according to electromagnetic laws." In short, Maxwell's theory assumes that the entire material universe lies in one all-pervading electromagnetic field, called for convenience *the ether,* and if this field be disturbed at any point, the disturbance is propagated throughout the field in the form of waves. All those forms of radiant energy which we call light, heat, etc., are in reality electromagnetic disturbances propagated in the form of electromagnetic waves.

Once an electromagnetic field is established, any change which alters the prevailing conditions is said to be an electromagnetic disturbance. When a current of electricity increases in strength, the field around it increases also, the lines of force spreading out from the conductor like ripples in a pond; but when the current is decreased, the lines of force contract, closing in around the conductor, and the energy of the field shrinks back into the system. If this process be augmented so that the periodic reversals of current produce oscillations of extremely high frequency, then, at each reversal, part of the energy of the field radiates off into the surrounding medium as electric waves and only part of it returns into the system. The frequency with which such periodic reversals of current take place determines the distance between the crests of the waves radiated into space from such a system. Waves created in the ether by this means are called *electric,* or *Hertzian, waves,* after the German physicist, Heinrich Hertz. Before entering upon a more detailed consideration of waves of this character, the subject of waves in general will be considered.

Nature of a Wave. When a disturbance is made at any point in an elastic medium, the particles of the medium are set into vibration and the vibrations are passed on to the neighboring particles, so that waves are formed; and these waves travel with a uniform velocity depending on the nature of the medium, with a result that the disturbance is propagated to considerable distances from its point of origin. There are in general two classes of waves, known as *longitudinal* and *transverse,* the distinction between them depending on the direction in which the particles vibrate. When the particles vibrate along the line in which the disturbance is traveling, the wave is said to be longitudinal; when the particles vibrate at right angles thereto, the wave is said to be transverse. The general equation for determining the velocity of waves of either class is

$$v = ln$$

where v stands for the velocity, l for the wave length, and n for the frequency, or number of vibrations per second.

This equation holds equally true for ether waves which manifest themselves as light, and for the longer waves produced by high-frequency oscillations of an electric current, both of which are of the transverse variety. Indeed all forms of radiant energy are, according to the present belief, due to ether waves, differing from one another only in length. As the velocity of propagation is the same for all—namely, 186,000 miles per second—the frequency varies through a wide range. Ether waves varying between certain definite lengths are visible and produce the sensation of light; others much longer falling upon matter raise its temperature, thus manifesting themselves as heat; still others, of a wave-length extremely small even in comparison with visible rays, are capable of penetrating matter as X-rays; and others again, of a length of half a mile or more, are flashed across the Atlantic, conveying intelligence from the Old World to the New.

As there are many methods of producing waves in gross matter, so also are there many methods of producing waves in the ether. The production of electromagnetic waves of a length measuring from a few inches to many rods need only concern us here, as it is with the production of such waves that the science of radiotelegraphy deals. As before stated, a part of the energy of a very rapidly alternating current is radiated off into space in the form of electric waves. Under what physical conditions such disturbances are created will now be considered.

Electric Oscillations. If a charged condenser, or Leyden jar, is discharged through a conductor of *high resistance*, the opposing polarities slowly neutralize each other by a current flowing in one direction. If, however, the condenser is discharged through a conductor of *low resistance*, such as a coil of wire of a few turns, the effect is wholly different. Under these conditions the discharge consists of a number of excessively rapid oscillations of the nature of a high-frequency alternating current, caused by the self-induction of the coil, in consequence of which the current once set up tends to persist. The first rush of current more than empties the condenser, and charges it to the opposite polarity; then follows a series of similar discharges of diminishing amplitude until the energy of the charge is entirely dissipated. This process is represented in Fig. 3.

The spark produced by the discharge of a condenser under these conditions appears to the eye as a single flash, due to the rapidity with which the successive discharges follow one another. In reality it consists of several distinct sparks lasting but an exceedingly small fraction of a second.

The law governing condenser discharges is as follows: *If a condenser of capacity K is discharged through a resistance R and self-induction L, the result is a uni-directional discharge or a series of oscillations according as R is greater or less than* $2\sqrt{\frac{L}{K}}$.

A rapid oscillatory discharge sets the electromagnetic medium in vibration much as a tuning fork sets the air in vibration in pro-

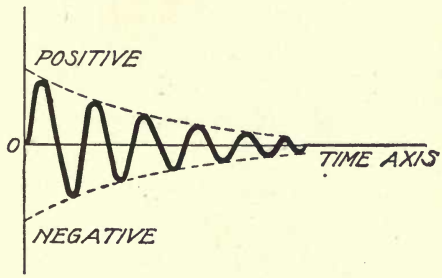


Fig. 3. Curve Representing an Oscillatory Discharge

ducing sound-waves. Such discharges provide a simple means for creating electric waves in the ether. An understanding of condenser action is, therefore, of great importance in a comprehension of the principles of radiotelegraphy.

The oscillatory nature of condenser discharges was known when Maxwell promulgated his electromagnetic theory, but it was not until twenty-five years after the announcement of the theory that scientists were able to detect the presence of electric waves. They knew the conditions under which such waves should arise, but none were able to devise a means to demonstrate their presence. It remained for Heinrich Hertz, a pupil of the illustrious von Helmholtz, to solve the mystery and give experimental verification to a theory which must ever remain one of the greatest achievements of inductive reasoning. Hertz succeeded not only in producing and detecting electric waves, but in demonstrating that such waves possessed all the essential characteristics of light.

The Work of Hertz. It was in 1888 that Hertz, then thirty years old and professor of Physics in the University of Bonn, carried

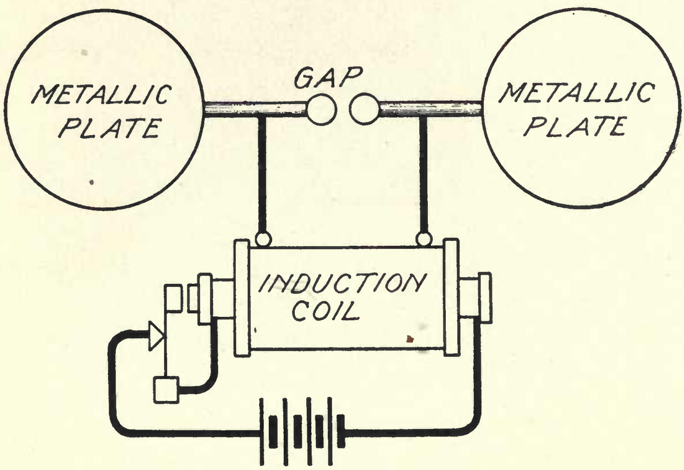


Fig. 4. Hertz Oscillator

on the epoch-making series of experiments which have proven to be the foundation of the art of radiotelegraphy. His apparatus was of the simplest construction. To generate electric waves he employed what is now known as a *Hertz oscillator*, Fig. 4. This consists of two metallic conductors in the shape of plates or spheres, each attached to a small rod terminating in a polished metal ball. These were connected to the secondary terminals of an induction coil and the two balls brought into close proximity, thus forming a small spark gap. It will be seen that the arrangement has the essential features of a condenser whose plates are widely separated and whose dielectric extends into the surrounding air. When the charge is accumulating on the large metallic plates, a strong electric displacement is set up between them, and, as the potential difference rises, a point is reached where the insulation of the air gap breaks down and a spark passes across the gap. During the passage of this spark the air becomes highly conductive and the whole oscillator becomes one conductor for the time being. The potential difference between the charged plates immediately begins to equalize itself, after the manner of all oscillatory condenser discharges, by a series of rapidly damped surges, and with every oscillation a wave is radiated into space. The waves emitted by a device of this character are intermittent, each complete discharge of the oscillator

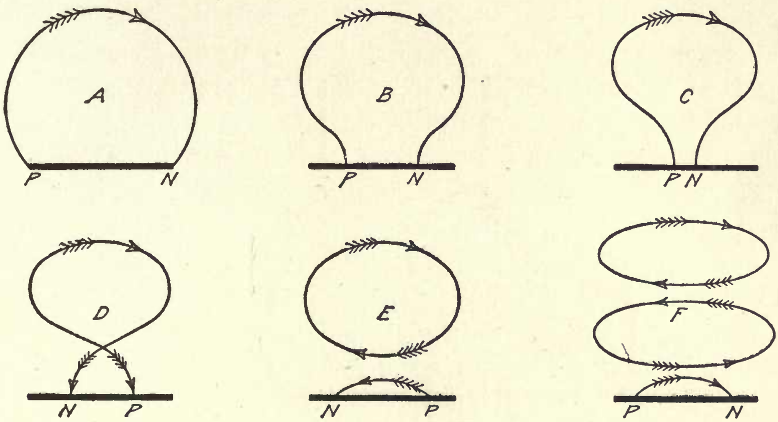


Fig. 5. Formation of Closed Loops of Electric Strain

sending out a rapidly damped train, or group, of waves. The frequency with which such trains follow one another depends upon the frequency of the charging source.

It cannot be said that the exact sequence of events in the formation of an electric wave is definitely agreed upon, further than that the production consists in sending out closed loops of force as shown by Hertz, Dr. F. Hack, and others. The subject is very difficult to present briefly, but an idea of the process may be had by reference to Fig. 5.

The curved line represents the form and the direction of one of the many lines of electric strain existing between the two plates of a Hertz oscillator. Every line of electric strain according to the electronic theory of electricity must be a closed line or loop, or else must terminate on an electron and a co-electron. The figures *A*, *B*, *C*, *D*, *E*, and *F* represent the successive stages in the production of closed loops of electric strain. As the charges oscillate to and fro the lines of electrostatic strain are crossed, making a closed loop which is immediately pushed outward by the following loop; with the result that the direction of strain around each loop is alternately in one direction and in the other, as shown in *F*. In addition to these lines of electrostatic strain there are at right angles to them other self-closed lines of force of a magnetic nature, due to the current passing during discharge. These magnetic rings of flux alternate in their direction at each oscillation, thus forming a series of closed loops of magnetic flux co-axial with the oscillator. Hence we are called upon to imagine the space around a Hertz oscillator as filled with concentric rings of magnetic flux periodically reversing in direction and having their maximum values at instants when the electrostatic strains are at their minimum values. These complementary modes of energy periodically varying in regard to time and space form an electric wave.

Energy of an Oscillator. As a portion of the energy imparted to an oscillator in the form of an electric charge is expended in heating the metallic balls, in creating a bright light, and in producing a noise at the discharge, it is evident that the entire energy of the system is not expended in the formation of electric waves. The total amount of energy which it is possible to potentially store in an oscillator in the form of electrostatic stress depends on its electrical capacity, and is equivalent to the amount of energy which could be stored in a condenser of the same capacity. The storage of energy in a condenser is proportional to the square of the voltage to which it is charged; which is another way of saying that a very great amount of energy could be stored in a very small condenser if it were possible to maintain the insulation under exceedingly high potentials. The dielectric strength of the material used for the dielectric thus places a limit upon the amount of energy it is possible to store in such a device. A small oscillator could likewise have a large amount of energy imparted to it by enlarging the spark gap enough to allow a higher potential to be reached before the insulation of the gap breaks down, were it not for the fact that the increased resistance of the lengthened gap renders the spark non-oscillatory.

A limit is therefore placed upon the potential which it is practicable to employ in the charging of oscillators or any form of condenser. As the capacity of a condenser increases in direct proportion to the area of its plates—other factors remaining the same—it is evident that the dimensions of an oscillator of the Hertz type determine the amount of energy it is possible to utilize in the generation of electric waves.

Hertz Resonator. The most important contribution of Hertz to the subject of electric waves was the discovery of a simple means for detecting the presence of such radiations. The fundamental character of the discovery is apparent when it is observed that the device consists simply of a single turn of wire forming a ring, provided with a spark gap between two metallic knobs, the distance separating these terminals being adjustable by a screw. The device, called a *resonator,* is shown in Fig. 6. Hertz discovered that electric waves falling upon such a conductor were capable of inducing therein alternating currents of the same frequency. By holding his resonator within a few yards of an active oscillator he found that it became the seat of induced secondary oscillations which were strong enough to be manifested by minute sparks visible between the metallic balls. Following up this clue he carried on a very extensive series of experiments, all tending to prove that such waves possessed all the characteristics of light—that they were indeed but "invisible light." Hertz' resonator may be said to be the first "wireless detector" known. The further development of this pregnant idea plays an important part in the evolution of the systems of wireless telegraphy.

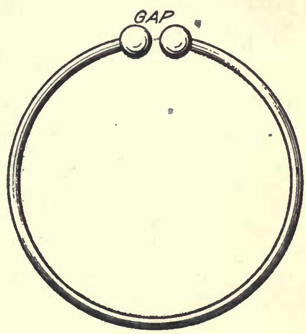


Fig. 6. Hertz Resonator

Resonance. A definite period of vibration is characteristic of many things in nature, including all sonorous bodies such as strings under tension, as in the case of the piano and all stringed instruments; confined portions of air, as exemplified by the organ pipe; and in fact all bodies which, when displaced by the application of an external force, tend to return by virtue of their elasticity and execute free vibrations until they gradually come to rest. If very feeble impulses be applied to a pendulum at rest at intervals exactly corresponding to its natural period of vibration, it may be made to swing through an arc of considerable amplitude. Bodies capable of executing vibrations by virtue of their own resiliency may likewise be set into powerful vibration by a series of impulses keeping time with their own natural period. Thus a tone from a violin may draw forth a responsive note from a piano, and by the same reason a piano will often set into sympathetic vibration some fixture or article of bric-a-brac. Also impulses communicated through the air from a sounding tuning-fork and falling upon another of the same pitch, will cause the latter to hum a note in unison. This phenomenon is called *resonance.* Resonance is thus an increase, or amplification, of a periodic motion by an intermittent force of the same time-period.

Resonant effects are not confined to the vibrations of gross matter, but may also be observed in connection with the flow of electricity in a circuit. This would seem to indicate that an electric circuit possessed something analogous to a natural period of vibration—which is the case. This time-period is due to certain characteristics of the circuit, namely *capacity,* and *inductance.* The quantity of electricity required to charge a conductor up to unit potential or, in other words, the ratio of the charge on a conductor to its potential, is called *capacity.* The unit employed to measure capacity is the farad. *Inductance* is that quality of an electric circuit by virtue of which the passage of an electric current is necessarily accompanied by the absorption of energy in the formation of a magnetic field. The analogy to mechanical inertia is very close, and, for convenience, inductance may be thought of as electromagnetic inertia by reason of which an electric current resists any sudden change. The unit of inductance is the henry. In all circuits possessing capacity and inductance there is a storage of electrostatic energy due to the potentially charged capacity, and a storage of electromagnetic energy due to the formation of the magnetic field by the current. Any electrical change taking place in such a circuit requires a readjustment of this stored energy. Such an adjustment takes place in the form of an oscillatory current of diminishing amplitude until equilibrium is restored. The time-period of such oscillations of energy is dependent upon the capacity and the inductance of the circuit, and is expressed by the equation

$$T = 2\pi\sqrt{LK}$$

where L is the inductance in henries, and K is the capacity in farads. The number of such oscillations per second, *i. e.*, the frequency, is, therefore, $n = \frac{1}{T}$. For purposes in connection with wireless telegraphy this equation is better expressed in microseconds, microhenries, and microfarads.

The phenomena of electrical resonance were first illustrated by Sir Oliver Lodge in his well-known experiment with his so-called *syntonic jars*. Two Leyden jars, Fig. 7, are placed a short distance apart. A bent wire connected to the outer coating of one serves as a discharging circuit (as shown) with a short air gap between polished knobs at the top. A circuit of wire whose inductance is rendered adjustable by a sliding cross-piece—making connection between two conductors—is connected permanently with a second jar. This

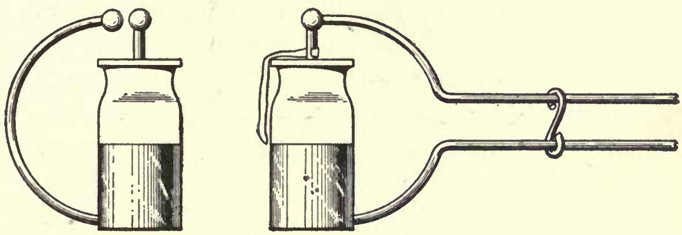


Fig. 7. Lodge Syntonic Jars

jar is also provided with a spark gap formed between the outer coating and a small piece of tin-foil extending from the inner coating over the lip of the jar to within a short distance of the outer coating. By continually discharging the first jar by connection with an induction coil or other suitable source of high potential, and by manipulating the sliding cross-plate in the circuit of the other jar, a point may be found where the latter will also discharge in syntony with the first. The two circuits are then said to be in tune, in syntony, or in resonance. When the product of inductance by capacity is the same for two circuits, they have the same natural period of oscillation.

As any circuit possessing inductance and capacity tends to oscillate electrically at its own frequency, it becomes the seat of an induced oscillatory current when subjected to the influence of electric waves of that frequency, each wave giving a slight impulse to the readily excited oscillations, with the result that the induced electromotive forces will be amplified in intensity, just as the swing of a pendulum is amplified by the application of properly timed, though feeble, touches. Circuits possessing inductance and capacity connected in series are thus capable of being "tuned" to a required frequency by a proper adjustment of these two factors. Such circuits are called *oscillatory circuits* and may be of many forms, but can be classified under two heads known as *closed* oscillatory circuits and *open* oscillatory circuits. Those circuits having their capacities in the form of condensers whose capacity areas are closely associated are called "closed," and those having their capacity areas widely separated in such a manner as to cause the field of electrostatic stress to extend out into the surrounding space are called "open." In the first, Fig. 8, the capacity is represented by the two metallic disks separated by a dielectric of air, and connected by a circular wire representing the inductance of one turn, while the "open" type, Fig. 9, is shown by the two metallic capacities connected by a rod which is cut in two at the center to form a gap. Either may or may not have an air gap introduced therein.

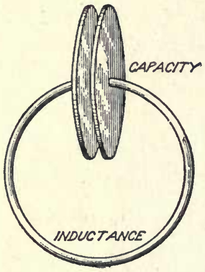


Fig. 8. Closed Oscillatory Circuit

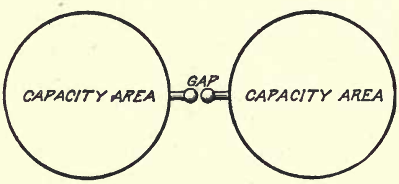


Fig. 9. Open Oscillatory Circuit

The similarity to the Hertz oscillator and resonator is apparent at a glance. This is, indeed, more than a similarity, for the Hertz oscillator was nothing more than an open oscillatory circuit, and his resonator a closed circuit of the same variety. By separating the plates of a condenser after the manner of a Hertz radiator, thereby forming an open oscillatory circuit, a large part of the energy of the charge is radiated away in the form of electric waves by reason of the dielectric extending out into the surrounding air. Circuits of this type are, therefore, excellent radiators but not very persistent radiators, because the oscillatory current is damped quickly by the rapid dissipation of energy in the radiation. Conversely, circuits of the closed type are persistent vibrators, but poor radiators. The train of waves emitted by the open type may be compared to the note given forth from a piano string when the finger is immediately removed from the key allowing the damper to rapidly extinguish the vibration. The closed type is comparable to a note struck on the same instrument but with the damper raised by the sustaining pedal. As it requires an increment of time to start oscillations in a tuned circuit, it is obvious that the closed type is preferable if it can be made to radiate sufficiently. If the damping of the oscillations in a radiator takes place too quickly, the energy of the charge will be dissipated at the first or second surge, in which event the exact tuning of a resonating circuit is unimportant. With a persistent oscillator, however, syntony between the two circuits is of the utmost importance, as otherwise the exciting circuit will tend to destroy at one moment the oscillations it set up a moment earlier. Syntony is of great practical value in the application of Hertzian waves to wireless telegraphy in that it permits of selective signaling to a certain extent by the employment of different wave-lengths, or the tuning of a receiving station to the frequency of a sending station.

Wave-Lengths. As before mentioned, the waves created by a Hertz oscillator are of very much lower frequency and are proportionally longer than light waves, but their velocity is identical. Furthermore, the relation between the velocity of propagation, frequency, and wave-length of ether waves was shown to be expressed by the equation

$$v = ln$$

In order to obtain numerical values for these quantities, it is evident that the value of v must be determined by reference to the best available experimental data. Numerous investigators have agreed upon 3×10^{10} centimeters per second as representing the most probable value for this constant. Knowing this, and by assigning the correct values to the factors *capacity* and *inductance* in determining the natural frequency, it becomes a simple matter to calculate the length of wave emitted by a radiator; and, conversely, by employing the proper capacity and inductance a radiator may be constructed to give any desired wave-length within wide limits. Capacity and inductance may be considered to be the electrical dimensions of an oscillator, and they determine the length of wave emitted, just as the note emitted from an organ pipe depends upon the dimensions of such a pipe.

The waves created by Hertz with various forms of his oscillator varied between a few inches and a few feet in length. He determined these lengths not only by mathematical computation as explained above, but by direct experimental test. He set up at the far end of his laboratory a large sheet of metal to reflect back the waves, and then went about the room with his resonator, exploring the space to find at what points sparks were produced. He found that when waves are thus reflected back upon themselves there are nodal points, just as there are nodal points in sound-waves and in light-waves when similarly reflected. Measuring the distances between these nodal points he was able to determine the wave-length precisely.

With the simple instruments at his command Hertz carried on many other experiments which are little short of beautiful in their adaptation of means to ends; but we cannot go into them here more than to say that they all tended to prove the main contentions of Maxwell's theory. The unqualified success of these experiments won the admiration of scientists all over the world. But few, if any, realized at the time that Hertz, in addition to giving indisputable proof to Maxwell's famous hypothesis, had also laid the foundations for a new and triumphant system of wireless telegraphy.

CHAPTER III

THE DEVELOPMENT OF RADIOTELEGRAPHY

It is evident that when Hertz constructed an apparatus which could transmit electrical manifestations to a distance, without wires, he possessed the elements of a system of wireless telegraphy. All signaling at a distance whether by wire or without, requires the presence of three fundamental factors: a device to produce the signal; a medium to carry the signal; and a device to receive the signal. Hertz' apparatus with its oscillator, electromagnetic medium, and resonator, easily fulfilled the requirements, and its use as a system of wireless telegraphy was merely a matter of time.

The main line of development was to be an extension of the distance over which signals could be transmitted; for as we have seen in the consideration of earlier systems—notably induction systems—distance is the important factor. Any system which cannot transmit messages to a considerable distance is of small practical service to the world. Hertz with his apparatus never succeeded in producing waves which were detectable at more than a score of meters or so; consequently we need not wonder that he never suspected that one of the largest fruits of his achievement was to be a system of wireless trans-oceanic communication. When asked by a civil engineer of Munich whether he thought telephonic communication could be effected bymeans of electric waves, he replied in the negative, as he considered that the alternations of current in the telephone were not of a nature to be detectable. He could not, of course, foresee the improvements which were destined to be made, rendering his apparatus immeasurably more sensitive and serviceable.

All the scientists of Europe were stirred by the announcement of Hertz' discoveries, and many set about to repeat the experiments. With so many minds bent upon a kindred purpose it is not surprising to learn that much new light was thrown upon the subject and many improvements made in the form and efficiency of the Hertz apparatus. Both the radiator and the detector were signally bettered.

The Righi Oscillator. One of the disadvantages of Hertz' radiator lay in the fact that the sparks in a short time oxidized the little knobs and roughened their surfaces, resulting in irregular action. Prof. Righi of Bologna overcame this difficulty by partly enclosing two metal spheres, *A* and *B* in Fig. 10, in an oil-tight case so that the outside hemispheres of each are exposed, the inner hemispheres being immersed in vaseline oil with only a minute gap between them. In a line with these spheres are ranged two smaller spheres, *C* and *D*, which form the secondary terminals of the induction coil. Thus three sparks are produced: one between *C* and *A*, another between *A* and *B*, and another between *B* and *D*. It is between *A* and *B* in the oil gap that the oscillatory spark takes place, the other two sparks serving merely to charge the large spheres. This arrangement not only produced a more constant spark by preventing the pitting of the electrodes but greatly extended the range of wave-lengths which it was possible to employ in investigations of this character. The dimensions of the oscillator could thereby be reduced and the amplitude of the oscillations greatly increased by reason of the fact that higher potentials could be reached before the energy was released by discharge. Righi obtained oscillations of a frequency of 12,000,000,000 vibrations per second by the use of small spheres *A* and *B* eight millimeters in diameter.

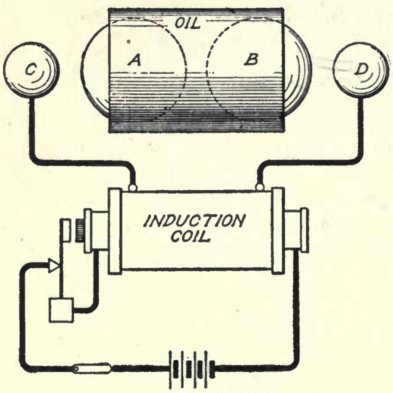


Fig. 10. Righi Oscillator

The Branly Coherer. The next important advance pertained to an improvement over the Hertz resonator as a means of detecting electric waves. It was based on the discovery of M. E. Branly and others, that the enormous resistance offered to the passage of an electric current by powders and metal filings is greatly reduced under the influence of electric oscillations. The resistance of such conductors may drop instantly from thousands of ohms to hundreds by the action of induced oscillations, retaining this conductivity until "decohered" by a mechanical blow. It will be readily seen that this provides a simple means of effecting the operation of a translating device by acting as a valve in turning on, as it were, a greater current in a local battery circuit. By utilizing this property of increased conductivity Sir Oliver Lodge succeeded in causing the deflection of a galvanometer. The device employed by Lodge consisted of a glass tube in the ends of which were sealed terminal wires connected to metallic electrodes of the same diameter as the tube, and between the electrodes was placed a small quantity of iron filings, as shown in Fig. 11. This device is known as a *coherer*, a name suggested by Lodge. In various modified forms the instrument has been employed up to the present day in different wireless systems. Its practical application will be fully considered later in connection with the work of Marconi.

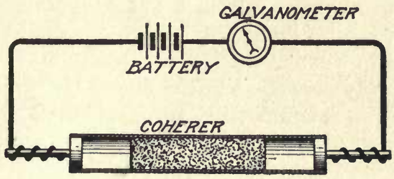


Fig. 11. Lodge Coherer

Radiotelegraphy First Suggested. As the Righi oscillator and Branly coherer were immeasurably more efficient than Hertz' corresponding apparatus, it necessarily follows that waves could be sent and detected over much longer distances and the time was getting ripe for the application of these devices to the purposes of wireless telegraphy. The first man to suggest this possibility is said to have been Sir Wm. Crookes, the eminent English chemist and physicist. In a magazine article which appeared in 1892 he made the following marvelous forecast of Radiotelegraphy:

> Rays of light will not pierce through a wall, nor, as we know only too well, through a London fog; but electrical vibrations of a yard or more in wave-length will easily pierce such media, which to them will be transparent. Here is revealed the bewildering possibility of telegraphy without wires, posts, cables, or any of our costly appliances. Granted a few reasonable postulates, the whole thing comes well within the realms of possible fulfillment. At present experimentalists are able to generate electric waves of any desired length, and to keep up a succession of such waves radiating into space in all directions. It is possible, too, with some of these rays, if not with all, to refract them through suitably shaped bodies acting as lenses, and so to direct a sheaf of rays in a given direction. Also an experimentalist at a distance can receive some, if not all, of these rays on a proper instrument, and by concerted signals, messages in the Morse code can pass from one operator to another.
>
> What remains to be discovered is—firstly, simpler and more certain means of generating electrical rays of any desired wave-length, from the

shortest, say a few feet, which will easily pass through buildings and fogs, to those long waves whose lengths are measured by tens, hundreds, and thousands of miles; secondly, more delicate receivers which will respond to wave-lengths between certain defined limits and be silent to all others; and thirdly, means of darting the sheaf of rays in any desired direction, whether by lenses or reflectors, by the help of which the sensitiveness of the receiver (apparently the most difficult of the problems to be solved) would not need to be so delicate as when the rays to be picked up are simply radiating into space, and fading away according to the law of inverse squares. . . .

At first sight an objection to this plan would be its want of secrecy. Assuming that the correspondents were a mile apart, the transmitter would send the waves out in all directions, and it would, therefore, be possible for anyone living within a mile of the sender to receive the communication. This could be got over in two ways. If the exact position of both sending and receiving instruments were known, the rays could be concentrated with more or less exactness on the receiver. If, however, the sender and receiver were moving about, so that the lens device could not be adopted, the correspondents must attune their instruments to a definite wave-length, say, for example, 50 yards. I assume here that the progress of discovery would give instruments capable of adjustment by turning a screw, or alternating the length of a wire, so as to become receptive of waves of any preconcerted length. Thus, when adjusted to 50-yard waves, the transmitter might emit, and the receiver respond to, rays varying between 45 and 55 yards, and be silent to all others. Considering that there would be the whole range of waves to choose from, varying from a few feet to several thousand miles, there would be sufficient secrecy, for the most inveterate curiosity would surely recoil from the task of passing in review all the millions of possible wave-lengths, on the remote chance of ultimately hitting on the particular wave-length employed by those whose correspondence it was wished to tap. By coding the message even this remote chance of surreptitious tapping could be rendered useless.

This is no mere dream of a visionary philosopher. All the requisites needed to bring it within the grasp of daily life are well within the possibilities of discovery, and are so reasonable and so clearly in the path of researches which are now being actively prosecuted in every capital of Europe, that we may any day expect to hear that they have emerged from the realms of speculation into those of sober fact. . . .

The purposes and problems of radiotelegraphy are admirably stated in the above. Some of those problems have not even yet been solved, as we shall see. When Crookes wrote, the idea of radiotelegraphy was in the air, and many men indeed were striving to turn the possibility into a reality. Several Englishmen almost achieved the desired end, but, strangely enough, faltered or failed when success was within easy reach. Among these, mention must be made of Prof. D. E. Hughes, who, but for a combination of bad luck and human fallibility, might have been today the accredited discoverer not only of radiotelegraphy but of electric waves as well.

Work of Hughes. As far back as 1879, when experimenting with his celebrated microphone (which is in reality nothing other than a Branly coherer reduced to its simplest elements) Hughes observed peculiar electrical effects operating at a distance, and he concluded that they were due to invisible electric waves. He did not, however, so far as we know, relate these phenomena with the theories of Maxwell, as Hertz did, and was consequently at a loss to fully account for them. He investigated the subject for several years and actually succeeded in telephoning wirelessly over considerable distances. These experiments were repeated before Prof. Stokes, the president of the Royal Society, and Prof. Huxley; but these gentlemen expressed doubts as to the nature of the phenomena, with the result that Hughes became infected with their scepticism and abandoned his efforts, believing himself on the wrong track. If he had persisted in his researches he might have gathered the laurels that later went to Hertz and Marconi. It has been said that "Hughes' experiments of 1879 were virtually a discovery of Hertzian waves before Hertz, of the coherer before Branly, and of wireless telegraphy before Marconi and others," and the truth of the statement must be admitted to some extent.

Work of Lodge. Mention must be made of the great debt which radiotelegraphy owes to Sir Oliver Lodge for his many valuable contributions both to practice and theory. He has been in the forefront of every advance made in the science of radiotelegraphy, and might in all truth be called its patron saint. To him is due our knowledge of the principles of syntony which forms such a vital part of all modern systems. He was the first man to employ the Branly coherer as a detector of Hertzian waves, and while engaged in demonstrating the discoveries of Hertz was sending signals over distances measurable in hundreds of feet. That such signals could be utilized to convey intelligence by the simple application of the Morse telegraphic code did not occur to him; if he had realized this possibility he might have antedated Marconi's invention of wireless telegraphy.

Work of Marconi. Passing over Popoff, Rutherford, Jackson, Minchin, and others, several of whom did important and original work, we come to Marconi who, in the popular mind, is credited with the whole achievement of radiotelegraphy. It is true that

Marconi carried radiotelegraphy through to practical success; or, as A. T. Story puts it, "he carried forward into the domain of practical reality what had only floated indistinctly before the minds of others, or had served them for modest experiments." But as regards those vital and fundamental developments of theory and practice without which radiotelegraphy would still be a thing unknown, Marconi is only an able follower and not one of the pioneers. The history of radiotelegraphy might be shortly indicated by the following list of names: Faraday, Maxwell, Hertz, Righi, Lodge, Marconi. The theory of electric waves originating with Faraday and expanded by Maxwell, was experimentally demonstrated by Hertz. Then came Righi and Lodge with their improvements on the Hertz apparatus, greatly extending its sphere of utility; and finally Marconi, who brought together the results achieved by his predecessors and, adding something of his own—"a far-seeing initiative where others had not gone beyond timid projects or tentative research"—produced a successful system of wireless telegraphy. Marconi, who is an Italian by birth, first became interested in Hertzian waves when a student under Prof. Righi at the Bologna University. He was not long in seeing their possible application to telegraphy, and made some experiments with that purpose in view. Becoming convinced of the feasibility of the project, but finding no one in Italy ready to take it up, he set out for England to try his fortune. Arriving there, he applied to the Patent Office for protection on his ideas, and then took the proposition to Sir Wm. Preece, chief of the British Postal Telegraphs. Preece gave Marconi ready encouragement, and he was soon conducting experiments under the auspices of the British Post Office.

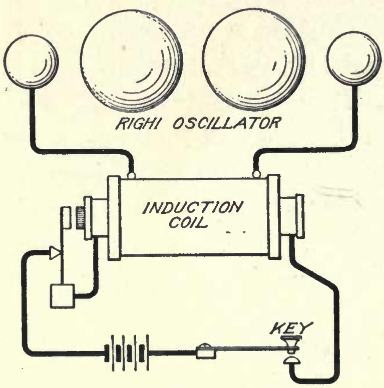


Fig. 12. Early Marconi Transmitter Circuit

Early Apparatus. The early apparatus of Marconi consisted essentially of a Righi oscillator and Branly coherer, disposed in suitable circuits for generating and recording the flow of waves. The transmitting arrangement consisted of an induction coil producing the requisite high potential with which to charge a Righi oscillator, and a Morse key of heavy construction with which to break the primary circuit of the coil, connected with a battery of about five cells. The actual transmission of messages was effected by the intermittent movement of the Morse key which, upon completing the circuit, started the interrupter of the coil which remained in

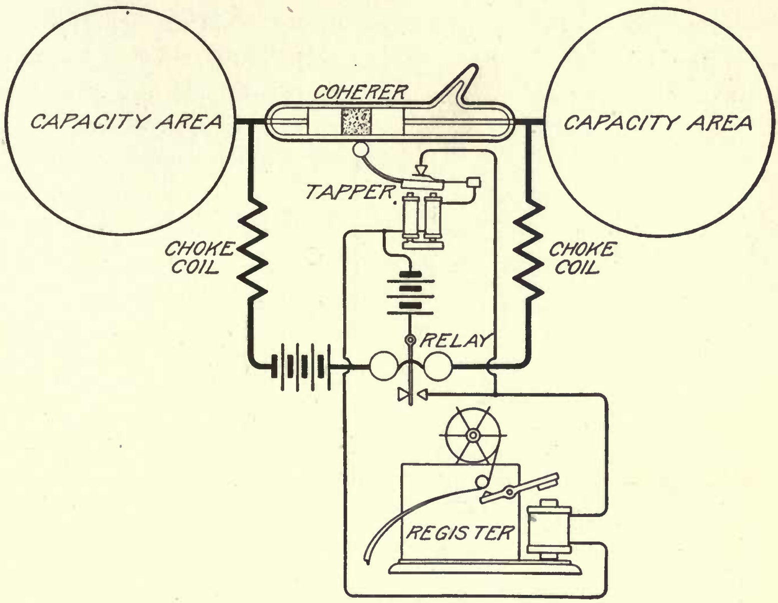


Fig. 13. Early Marconi Receiving Circuit

operation as long as the key was held down; thus the duration of waves from the oscillator was made dependent on the position of the key. It was thus possible by the proper manipulation of the key to send a series of long or short wave trains corresponding to the dots and dashes of the Morse alphabet. Fig. 12 represents diagrammatically these features of the sending station.

The receiving apparatus, indicated in Fig. 13, consisted principally of the Branly coherer somewhat modified in construction and associated with suitable auxiliary apparatus for recording the duration of the received wave trains in the form of dots and dashes upon a moving paper surface after the manner of the Morse recorder, well known in wire telegraphy. As the coherer retains its low conductivity even after the cessation of a train of waves, it becomes necessary to provide means for automatically imparting a slight blow or jar to the tube in order to restore its receptiveness after each and every signal. Such a device was used by Lodge and is known as a "tapper." It is generally in the form of an electric trembling mechanism, such as an electric bell, operated by a local battery when thrown into the circuit by a Morse relay—the latter acting in response to the increase of current when the coherer acts.

The coherer used by Marconi at this time was his own special modification of the Branly-Lodge type. It consisted of a glass tube

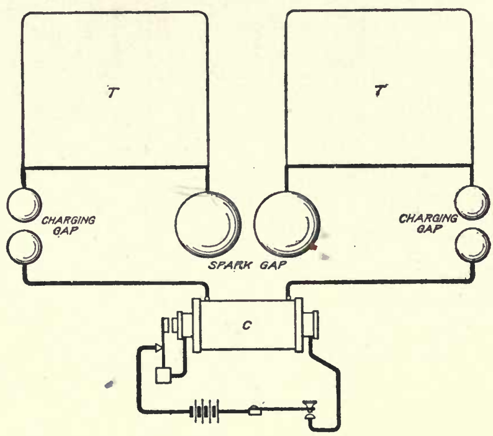


Fig. 14. Marconi "Capacity Areas"

about 4 centimeters long and 2.5 millimeters in diameter, into which were tightly fitted two silver terminals separated to a distance of one millimeter, this space being filled with a powdered mixture of 96 parts nickel to 4 parts silver, worked up with a trace of mercury. The tube was exhausted of air and hermetically sealed. To the terminals of this coherer were connected two resonance plates, or strips of copper, whose dimensions were such as to bring the system into resonance with the oscillator. Also connected to the terminals of the coherer were two choke coils, whose function was to confine the oscillations to the coherer; and a Morse relay in series with a battery of one cell. Fig. 13 plainly shows the arrangement.

In addition to the above a tapper was provided to decohere the metal filings, and also a signal recorder. The tapper was in the form of a small electric-bell mechanism whose clapper continuously tapped the glass tube as long as the Morse relay completed the circuit in which the tapper was placed. The Morse relay thus acts as a switch by means of which the signal recorder and tapper are operated simultaneously. It might be well to state that the coherer holds its conductivity during the passage of the oscillations even though in vibration from the tapper.

Capacity Areas. A very significant step taken by Marconi at this early period was his employment of "capacity areas" in the circuit of his oscillator, Fig. 14. The essential features of this innovation were as follows: *T* and *T* are metal plates joined to the balls of the oscillator; *C* is the induction coil. The object of this arrangement was to give greater energy to the oscillations, the carrying power of the apparatus being found to increase with the size of the capacity areas, and with the distance of the same from each other. Two similar plates were also attached to the coherer at the receiving station. Though this arrangement of capacity areas was soon abandoned, it marks, nevertheless, the inception of an idea which developed, as we shall see, into one of the most important features of modern aërial telegraphy, namely, the antenna.

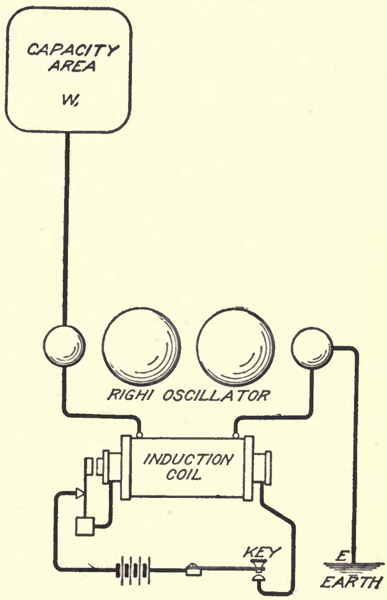


Fig. 15. Diagram Showing the Earthed Oscillator

Development of the Antennae. Endeavoring to increase the effectiveness of his capacity areas by enlarging them and separating them as much as possible, Marconi conceived the idea of utilizing the earth for one of the plates, and of raising the remaining plate to a considerable height in order to increase the distance between them.

The arrangement, Fig. 15, then took on the following aspect: coil and oscillator are of standard type; *E* is the earth connection; and *W* the elevated plate. The higher the capacity area *W* is situated, the greater the distance to which communication can be carried; so it will be seen that the capacity area might with great advantage be attached to a kite, or captive balloon. The latter were, indeed, employed by Marconi and with very good effect. Corresponding changes were made at the receiving station also, by employing a similar arrangement of capacity area, shown in Fig. 16.

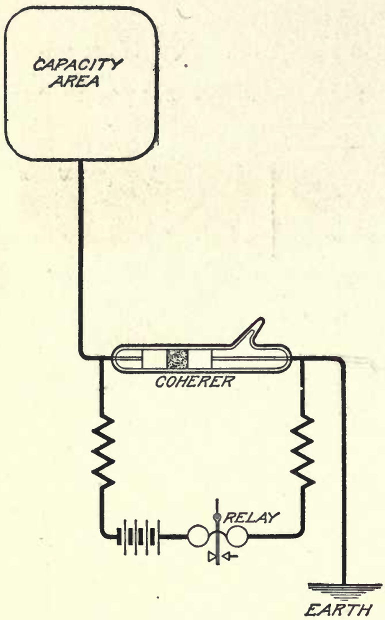


Fig. 16. Earthed Receiving Circuit

Later Marconi became convinced that the effectiveness of his aërial line was due not to the capacity at the end of the wire, but to the length of the wire itself; consequently he abandoned the capacity area altogether and held simply to the form of vertical wires attached to poles or kites, or even to high buildings or towers. These were called antennae, or aërials. The antenna consisting of a single wire later developed into the multiple antenna of several wires, each additional wire adding to the capacity of the system. The antennae of many large stations are formidable structures of great complexity, as the picture of the South Wellfleet station, Fig. 17, will indicate.

Inductive Receiving Antennae. Another of Marconi's early and important modifications was the introduction of inductive antennae into the receiver arrangement. The antenna was cut out of direct conductive connection with the coherer circuit and allowed to act on the latter only by induction through the agency of an oscillation transformer called in common parlance a *jigger,* the theory of which cannot be fully discussed here. Mention will be made, however, of the fact that such a transformer properly designed in regard to the wave-length used not only steps up the voltage so as to increase its effect on the coherer, but also enables the coherer to be placed at a nodal point of the secondary oscillations. As this form of detector

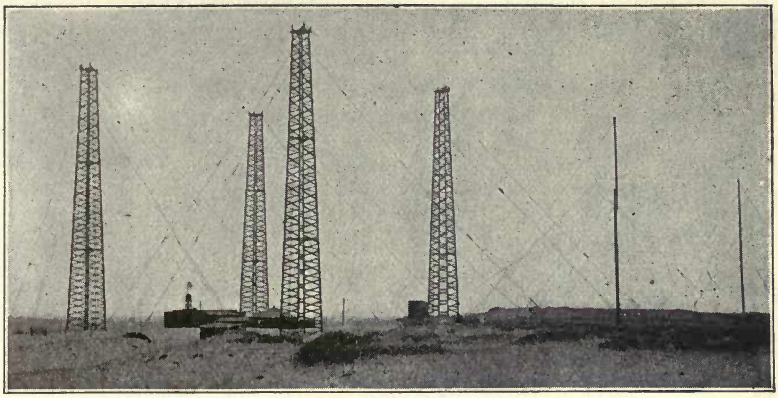


Fig. 17. South Wellfleet Wireless Station

is of the potentially operated variety, the practical importance of the modification is apparent. A coherer placed in series between the antennae and ground, as in former arrangements, is poorly located, as at the base of an aërial the potential is a minimum and the current a maximum. Marconi increased the distance over which it was possible to signal nearly ten times by the employment of this simple

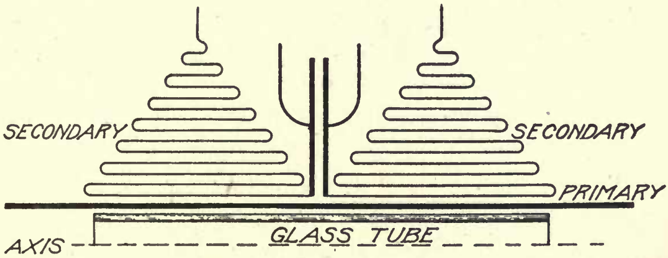


Fig. 18. Diagram of Oscillation Transformer Winding

device. His patents on this improvement bear the dates of 1898 and 1899. Fig. 18 shows a diagrammatic cross-section of the jigger, the zigzag lines representing the successive layers of the windings wound in such a manner that the inner layers have the greatest number of turns, the primary having about 100 and the secondary about 1,000 turns. Fig. 19 shows the receiver-circuit with the jigger embodied therein. It will be noticed that the local-battery circuits are the same as used before, but the jigger necessitates a slight modification in the location of the coherer. A condenser is connected to the inner terminals of the secondary, the outer terminals of which are connected to the coherer. The local battery circuit is also connected to the inner ends of the secondary and across the condenser.

Inductive Transmitting Antennae. It has already been shown that the early capacity areas had given place to the extended wire raised to a great height; and it soon became evident that transmission could be further facilitated by devising a more persistent oscillator than that which was employed with the directly connected aërial. It was possible to store a fair amount of energy in the old type of aërial, but the direct connection entailed the disadvantage of permitting the apparatus to radiate its entire amount of energy almost instantly instead of radiating such energy in the form of a more continuous train. This was not a quality tending to make for a clearly defined resonance between the sending and receiving circuits, and means were sought to accomplish a more persistent, or less damped, series of oscillations. The early form of open-circuit oscillator, therefore, gave place to what is known as the Marconi-Braun type of closed oscillating circuit which, while not so powerful a radiator, was a very much more persistent one. The method was due to Prof. Braun, but in a modified form was first used by Marconi. The diagram of Fig. 20 makes clear the fundamental idea, an idea which has proven to be of great value. Though modified in numberless ways by subsequent inventors, the broad idea of associating the aërial with a closed oscillating circuit has become almost universal.

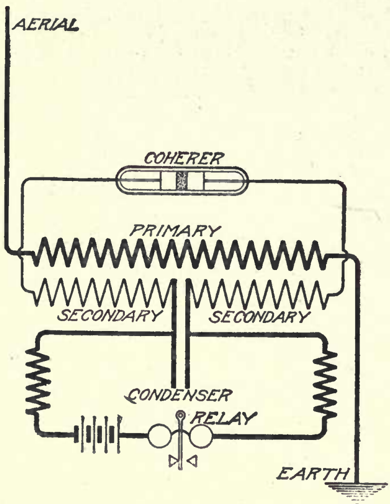


Fig. 19. Marconi Receiver-Circuit with Jigger

The transformer used for this purpose is very different from the ordinary induction coil or alternating-current transformer employed in connection with low voltages and low frequencies. It will be fully described later under the head of oscillation transformers; for the present it is sufficient to say that it forms an inductive couple between the two oscillatory circuits, the closed circuit being but a means of charging the open circuit of the antennae. The antennae circuit, having a certain amount of capacity and inductance depending on its design and position, possesses a natural time-period of its own; so in order to induce in such a circuit oscillations of a maximum amplitude, the primary circuit associated therewith must have the same natural time-period. In other words, resonance must be established; two circuits, as before mentioned, being in resonance when the product of capacity and inductance is the same for both. The Marconi-Braun method of charging the aërial permits of the employment of very large capacities, with proportionally larger energy-storing ability and smaller inductances in the primary circuit, so that the product of these two factors can be made to equal the product of the corresponding factors in the antenna circuit. The efficiency of the transformer thus very largely depends on the establishment of syntony between the closed oscillatory circuit forming the primary and the open oscillatory circuit forming the secondary.

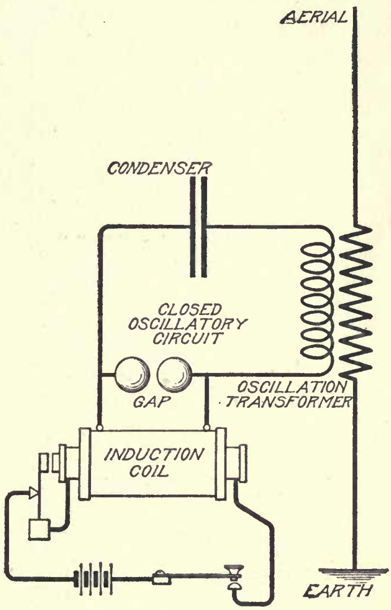


Fig 20 Marconi-Braun Inductive Transmitting Antennae

Another method of associating the radiating aërial with a closed oscillatory circuit, possessing many of the advantages of the Marconi-Braun inductive couple, is shown in Fig. 21, and is known as the direct-coupling method. An inductance of several turns of wire is, in effect, introduced in series with the aërial and the ground. A certain portion of the inductive turns is included in a closed oscillatory circuit composed of a condenser and spark gap shunted around the said portion. When the closed energy-storing oscillatory circuit and the open radiating circuit of the aërial are adjusted to the same periodicity the scheme becomes effective. The method of direct coupling has been subjected to many changes at the hands of inventors, in some cases becoming almost unrecognizable, but upon analysis the fundamental idea shows through. It is to be noted that with both the direct and inductively coupled systems, syntony between the open and closed circuits is essential.

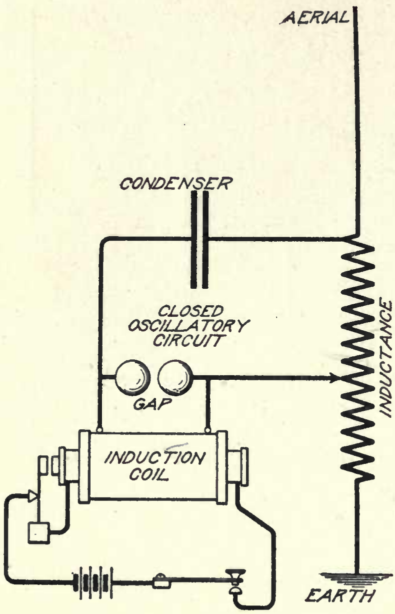


Fig. 21. "Direct-Coupled" Inductive Antennae

Both of the foregoing arrangements allow the possibility of creating in the aërial far greater charging electromotive forces which, in properly proportioned antennae, increase toward the top where they may reach a value equivalent to hundreds of thousands of volts in the larger installations. Hence, with the adoption of this form of transmitting arrangement, it became possible to radiate a series of well-sustained oscillations of much greater energy than ever before, thus still farther extending the distance to which communication could be carried. This improvement may be said to be one of the greatest advances in the history of radiotelegraphy.

Propagation of Waves from a Grounded Oscillator. The theory of the propagation of electric waves from a Hertz oscillator before given, assumed a perfectly symmetrical isolated oscillator suspended in space. The employment of the grounded oscillator in the form of an earthed aërial now exclusively used in radiotelegraphy necessitates a modification of the above theory in order to meet the problems arising under the changed conditions. The new arrangement was, in effect, the substitution of the earth for one of the capacity areas of a Hertz radiator, and the extension of the companion area into a vertical wire possessing capacity with regard to the earth from which it is separated by an air gap. The type of wave radiating from such a system differs in many respects from the form of disturbance emanating from a simple isolated oscillator, and presents theoretical difficulties which cannot as yet be said to be satisfactorily explained. The electric waves from a grounded oscillator apparently follow the curvature of the earth. One of the theories purporting

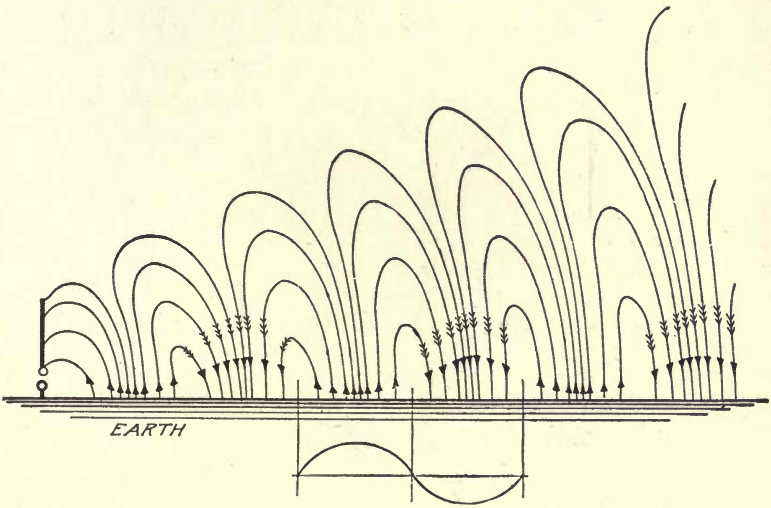


Fig. 22. Diagrammatic Representation of the Sliding-Wave Theory of Propagation

to account for this phenomenon assumes that such waves are not ordinary free electric waves consisting of closed loops of electric strain, but on the contrary consist of half loops traveling over the surface of our globe with their ends remaining always in contact with the surface. This view is supported, it would seem, by the electronic theory of electricity. It is roughly represented in Fig. 22. The detached semi-loops of strain are shown by the lighter lines, and the simple grounded oscillator by the heavier. A wave-length would be represented on the horizontal line by the distance included between any two positions thereon where the direction and intensity of strain (shown respectively by the arrows and the proximity of the lines) is identical. This is the *sliding-wave theory,* said to have been first promulgated by J. E. Taylor. Other theories have been advanced to account for the wave-transmission following the curvature of the earth, one such assuming that the waves are radiated in a straight line but reflected back from a semi-conductive envelope formed by the upper strata of the earth's atmosphere.

Selective Signaling. The problem of directing a message to its proper destination was felt by early investigators to be of vital importance, if radiotelegraphy was ever to be a commercial success. Some method must be discovered to effect selective signaling—else how would it be possible for a plurality of stations to be transmitting at once? The solution of the difficulty was thought to be found in the principle of resonance.

The history of the subject records at a very early date efforts to achieve the desired end by employing definite wave-lengths corresponding to the electrical time-periods of the various stations it was desired to place into communication. Thus among a plurality of active sending stations any number might communicate simultaneously in pairs without interference by arbitrarily assigning a definite frequency, or wave-length, to each pair. Selection by this method assumes that it is possible to "tune" receiving instruments so they will respond to a particular "pitch" and to no other; but as the number of possible non-interfering wave-lengths is limited, it cannot be said that resonance offers an entirely satisfactory solution of the problem.

By the employment of two or more receiving circuits connected to the same aërial, each tuned to a different frequency corresponding to as many different sending stations, the simultaneous reception of two or more messages is theoretically possible. As early as 1900, Marconi achieved some very remarkable results of simultaneous non-interfering communication when he received by the same aërial two messages, one in English and the other in French, which were simultaneously transmitted over a distance of 30 miles.

It was to be expected that the last few years would bring in their train great improvements in this respect as well as in others, so that it may be said today that selective signaling is feasible to a certain extent and that the remaining obstacles will be removed by further developments of the art; but until those advances are made, so that much more can be accomplished with respect to selective signaling than at present, the field of operation for radiotelegraphy will be confined mostly to communication between ships, between ships and shore, and across large bodies of water.

Conclusion. The application of Hertzian waves to the purposes of telegraphy as outlined above, covers what might be called the foundation and early development of the art. Every step taken at this early period was vital and significant. Since then enormous advances have been made; the distances over which it is possible to telegraph have been greatly extended, and the apparatus rendered more sensitive and certain in every way; but these results have been accomplished more by a refinement of detail—the development of more sensitive instruments, and the closer connection between theory and practice—rather than by the application of fundamentally new ideas. The twentieth century ushered in a new and tentative method of telegraphic communication called radiotelegraphy, and the first ten years have witnessed its establishment as one of the permanent adjuncts of civilization.

CHAPTER IV

RADIOTELEGRAPHIC APPARATUS

It is obviously impossible within the scope of the present work to give a detailed description of all the apparatus pertaining to radiotelegraphy. In view thereof it is assumed that the reader is familiar with the ordinary instruments and physical appliances commonly used in electrical work and not in any way peculiar to wireless telegraphy. It is also assumed that the elementary facts of electrical phenomena are known. The descriptions of the apparatus in this chapter will be given without reference to their grouping together in the formation of a complete system, but will be given singly with such theoretical considerations as may seem necessary. The chapter following will be given over to the assembling of apparatus into complete systems under their proper appellations, together with some account of their performance.

Sources of Energy. In any system of radiotelegraphy the prime desideratum is to associate with the aërial a maximum amount of energy available for radiation. It was early recognized that the most obvious way to accomplish this was to increase the capacity of the aërial or to employ condensers associated in various ways in order to store temporarily the electrical energy to be radiated. The main function, therefore, of the source of energy employed in the transmitting station is to properly charge a given capacity. The greater this capacity, the greater the amount of initial energy required. Expediency determines largely the nature of the source of energy, whether derived from storage batteries, a generator, or from power mains. The energy consumption ranges from a few watts up to 50 to 100 kilowatts, so it is evident that the sources of current are subject to a wide range of choice. The trans-Atlantic stations of Marconi at Cape Breton employ generators of 65 horse-power.

Charging Devices. To create the required electrical oscillations in the aërial, it is necessary to have appliances which shall generate the requisite high-potential electromotive forces for charging the aërial and its associated capacity. Such an appliance should create not only a high potential but also an appreciable current. This charging e. m. f. is generally effected by the use of the induction coil or the alternating-current transformer.

Induction Coils. It is not deemed necessary to give an extended discussion of the induction coil, but to call attention to the important modifications to be incorporated therein for use in wireless telegraphy. The purpose for which the coil is employed is to charge a condenser of some form rapidly. The time required for a condenser to attain the same potential as the charging source to which it is connected depends largely upon the resistance of the charging source. In order to secure a small time-constant for the charging circuit, it is highly desirable to have a secondary of as low resistance as possible. The lower the resistance of the secondary, the greater the capacity that can be rapidly charged by a coil of a given number of turns. It must be borne in mind that, in order to charge a condenser to a given potential, current is required. The usual small induction coil is wound with very fine wire on the secondary—No. 36 or finer. It goes without saying that this is not at all suited for use in wireless telegraphy. Considerable data on coils suitable for the use herein considered is available. The core should be composed of well-annealed, Swedish soft iron wire of small diameter—about No. 24—wound with a primary of comparatively few turns of coarse copper wire—about No. 12—double cotton-covered and well insulated from the core. It is not practical to wind the secondary with coarser wire than No. 32 or No. 33 B. & S. gauge. Special attention should be paid to the insulation of the secondary as it is of great importance that this be able to withstand the high impulsive electromotive forces of short duration which occasionally manifest themselves. Late design seems to be in the direction of longer cores—about twice the length of the secondary winding.

Tesla called attention to a fact of importance in connection with induction-coil design, as far back as 1893, viz, that a condition of resonance between the primary and the secondary circuits greatly adds to the efficiency of the device. This has the practical result of greatly decreasing the resistance of the secondary and also the number of turns, with a result that much more current is deliverable from such a coil. In the primary circuit there is usually large capacity and small inductance, while in the secondary there is small capacity and large inductance.

Even with the above added efficiency, induction coils are not as suitable in many respects for commercial radiotelegraphy as alternating-current transformers. The utility of the induction coil is limited by reason of the fact that the details of design are so largely a matter of compromise that it is impracticable to obtain the desired charging current at the required voltage. The efficiency of induction coils is at best but slightly above 50 per cent, and there are reasons for believing it much lower.

The three important adjuncts of the induction coil are the primary condenser, the interrupter, and the signaling key.

Primary Condenser. The principal function of the primary condenser is to absorb the energy that manifests itself at break in the form of an arc, due to the self-induction of the primary circuit. As the secondary e. m. f. is due largely to the suddenness of the rupture in the primary, it is of the utmost importance that this arc be prevented from forming. The primary condenser is, therefore, placed across the break in such a manner as to be short-circuited when the circuit is closed, but at the instant of break it is placed in the circuit and absorbs the energy which would otherwise be dissipated in the formation of an arc, and which would very greatly increase the time of rupture. Fig. 23 indicates the arrangement of the circuit. The best value for the primary condenser is that capacity which will annul to the greatest degree the sparking at the points of the interrupter. Experiments have shown that if the primary be broken with sufficient rapidity, as for instance with a rifle ball, no condenser is needed. A condenser is not needed with a Wehnelt interrupter.

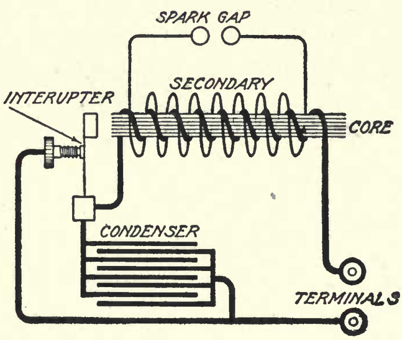


Fig. 23. Diagram of Induction Coil Showing Condenser Circuit

Interrupters. Interrupters perform the sole function of causing a rapid succession of sudden breaks in the primary circuit. The commonest as well as the oldest form of break is known as the *hammer* *break*, probably invented by Neef. Its action is perhaps best shown by referring to the common electric door-bell. An electromagnet, in attracting an armature, causes an interruption of the current energizing the electromagnet, whereupon the armature falls back by reason of its spring tension and again completes the circuit; this energizes the magnet once more, which again attracts the armature, and the whole operation is repeated. The armature is thus kept in continual vibration with consequent interruptions of the current. Fig. 24 shows this device—which is subject to almost endless variation —in a form having as one of its decided advantages the ease with which it is adjusted by simple regulation for different frequencies. Fig. 25 shows another form with the contacts made in small cups of mercury, known as the *Foucault break*. It is obvious that the break can be produced independently of the current in the primary circuit by means of a small electric motor acting on a lever which is made to dip into a cup of mercury, thus completing the circuit any desired number of times per revolution. Such a break is called the *motor break*. The rotary, or turbine, break has been used very successfully on large coils requiring considerable amperage for their operation. The simple hammer break does not operate well with voltages over 16 or 20; therefore, when it becomes necessary to utilize commercial pressures such as 110 and

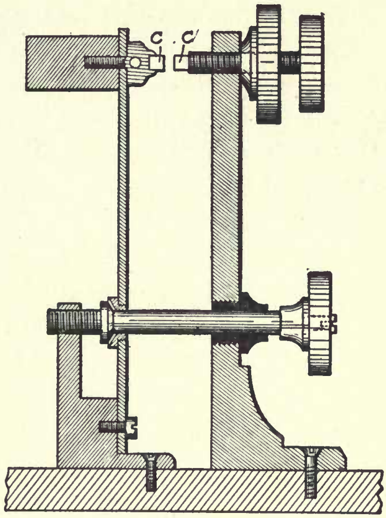


Fig. 24. Neef Hammer Break

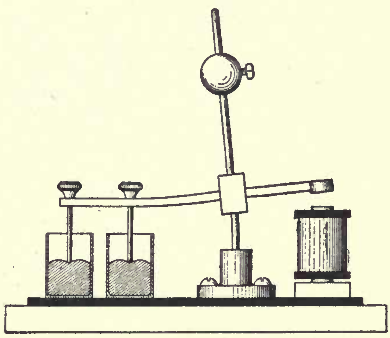


Fig. 25. Foucault Mercury Break

220 volts, some form of mercury turbine interrupter is found to be preferable. One form of this interrupter is shown in Fig. 26.

Dr. Wehnelt of Charlottenburg invented, in 1899, a form of interrupter for use with induction coils, operating on an entirely different principle from those described above. Taking two electrodes of very different size, such as a large lead plate and a small piece of platinum wire projecting from the end of a closely fitting glass tube, and placing them in an electrolyte of dilute sulphuric acid, he discovered that an electrolytic action takes place when the

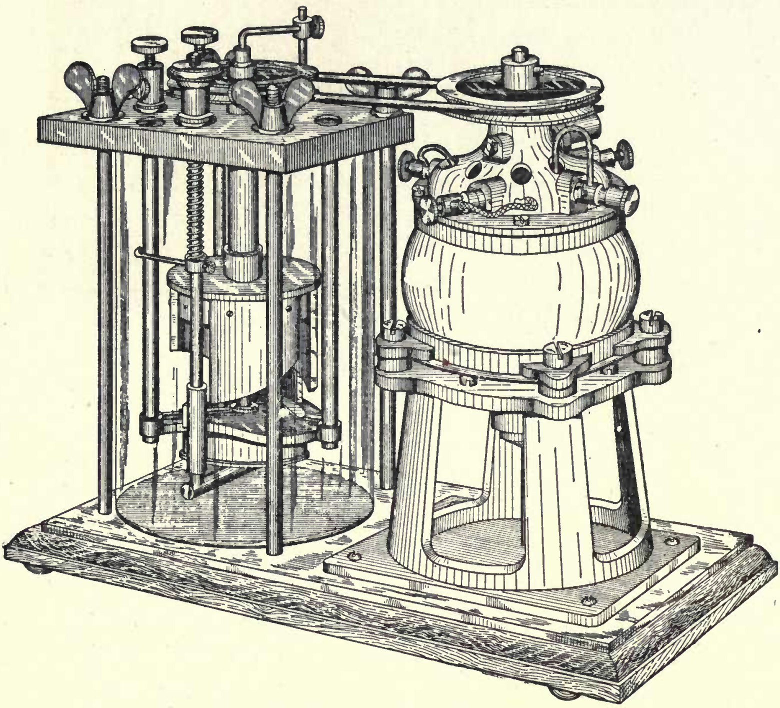


Fig. 26. Mercury Turbine Interrupter

large lead plate is made the negative pole, this action interrupting the current periodically when the device is connected to a source of 40 to 80 volts. Fig. 27 gives an idea of the device, showing one of the many modifications it has undergone in its commercial design. The positive platinum electrode can be seen protruding slightly from the end of the porcelain insulating tube immersed in the liquid, which must be a solution of about one part sulphuric acid to ten parts of water. The cut shows a water-cooling jacket, which is an advantage as the apparatus becomes very warm under continued use. Experiments have shown this device to be capable of producing an intermittency of over 1,800 per second. As mentioned above, no condenser is necessary when operating an induction coil with this form of interrupter. The character of the secondary discharge is somewhat changed by the use of the Wehnelt cell, rendering it more like the alternating arc than the usual disruptive spark. It cannot be said that an entirely satisfactory theory has ever been given for the action of this cell. The Wehnelt interrupter has not been used very commonly in connection with radiotelegraphic work, its greatest field of usefulness being in Röntgen ray work.

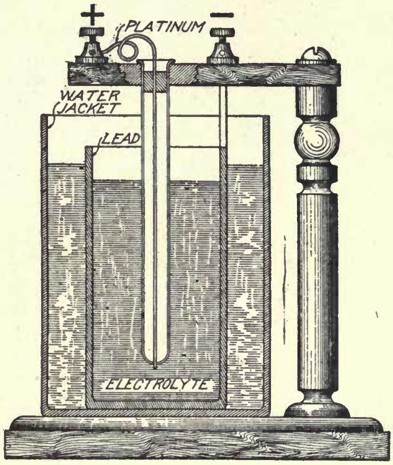


Fig. 27. Wehnelt Interrupter

Keys. In order to transmit messages by means of an arbitrary code consisting of long and short trains of waves representing the Morse alphabet, an adequate means of controlling the torrent of sparks between the electrodes of the spark gap must be employed. The key problem in this form of telegraphy is somewhat more complicated than in the ordinary wire systems, primarily by reason of the fact that a much greater current must be controlled. The common Morse key need not open more than a fraction of an inch, $\frac{1}{64}$ being ample; but it becomes necessary in wireless work to rapidly break currents of several amperes in circuits of considerable inductance, under which conditions the Morse key would not answer at all. The speed of signaling depends largely on the rapidity of the key, a wide movement greatly cutting down the efficiency of the system as a means of communication; therefore, short-range keys must be provided, with some means of annulling the heavy spark on break. Many suggestions have been made and a number of patents taken out purporting to accomplish this end. The magnetic blow-out has proved the most generally useful; though some systems employ a short-circuiting resistance around the break, and others a condenser to absorb the arc. One form of Marconi key simultaneously breaks the primary current and disconnects the aërial from the transmitting apparatus. Many keys are designed to cause the break to take place under oil or other highly insulative substances. Lodge and Muirhead employ an electromagnetically operable key which is actuated by current in a local circuit interrupted by an ordinary Morse key. A common form of such a key, which is of very heavy construction and of extra wide movement, is shown in Fig. 28.

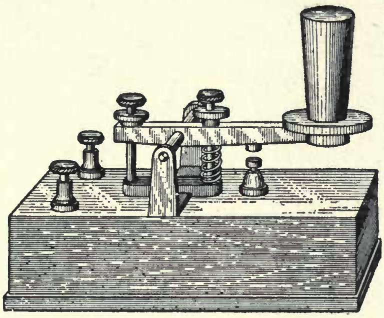


Fig. 28. Long Range Morse Key

Alternating-Current Transformers. In nearly all high-power stations it has been found advantageous, if not absolutely necessary, to discard the induction coil as a means of charging the high capacities used, substituting the alternating-current transformer. This involves the employment of an alternating-current as the initial source of power. Transformers designed for this purpose are wound for a high ratio of transformation, generally for a secondary voltage of at least 20,000 volts, and often 30,000 to 50,000. A difficulty experienced with the use of the transformer is the liability of forming an alternating arc between the balls of the gap in place of the proper oscillatory spark. The practical short-circuiting of the transformer by this action causes a great rush of current through the primary, which, if it has not been guarded against, is liable to cause great havoc with the generator, blowing out the fuses and possibly working other damage more serious. When the capacity of the condenser is of the exact value to take up in the form of a charge nearly the entire energy of each half-wave of the periodic current, no alternating arc will arise and the discharge across the gap will be due entirely to

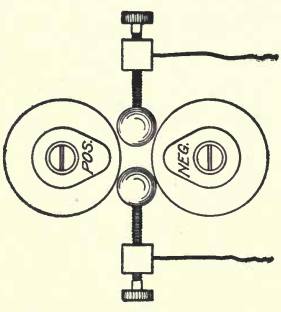


Fig. 29. Tesla Magnetic Blow-out

the condenser, in which case no external means for extinguishing the arc are necessary; but this relation is very hard to effect permanently, so that numerous plans have been devised to prevent the formation of this arc. The one due to Nikola Tesla, which has undoubtedly proved to be the best, utilizes a strong electromagnet so that its lines of force pass transversely between the spark gap. This arrangement is called a *magnetic blow-out.* Fig. 29 shows the scheme. Elihu Thomson achieves the same end by directing a strong blast of air on the gap from a nozzle. This permits the oscillatory spark to form at the proper time, but completely extinguishes the alternating arc, or rather prevents its formation. The noise incident to the operation of a large transformer producing a heavy oscillatory spark is deafening and some precaution must be taken to protect the ears of an attendant if the gap is not enclosed. The light from such a spark is also very hard on the eyes.

Oscillation Transformers. Transformers designed for high-frequency, high-potential, oscillatory currents are in many respects different from the transformers suitable for use on low-pressure, low-frequency, electric-light mains. The most striking difference is the absence of an iron core and the small number of turns of wire employed. The transformer used by Marconi with the Marconi-Braun type of closed oscillator was constructed as follows: The primary consisted of but one turn on a stranded conductor of low resistance with a secondary of thinner wire laid over the primary in about ten turns. The coils were immersed in highly insulating oil. In commercial practice oscillation transformers are of various design. It is of the utmost importance that transformers of this character be specially well insulated, particularly when the primary and the secondary are in close inductive relation. The use of oil in this connection is the common practice. Late forms of oscillation transformers are made in such a manner that the distance between the primary and the secondary may be varied, thus alternating their inductive relation, a so-called "loose couple" being produced by separating the two components.

Condensers. The condensers employed in radiotelegraphy, as in other departments of electro-technics, are chosen with regard to the voltages to which they are to be subjected. The capacity used in connection with receiving circuits requiring no high insulating properties generally takes the form of paper or mica condenser supplemented by a variable-capacity condenser consisting of a number of fixed metallic plates interspaced in air between an equal number of moveable plates, whereby the effective capacity areas of the plates may be varied within wide limits.

In the transmitting circuit where the condenser is employed to temporarily store the energy preparatory to the sending of a signal, a form of condenser must be used which will withstand the electrostatic strain of a very high potential. This necessitates the use of glass, mica, or oil, as experience has proved these materials to be almost the only dielectrics practicable for the purpose, glass being, all things considered, the best of all. The higher the voltage, the greater the thickness of glass needed; and as the storing power of a

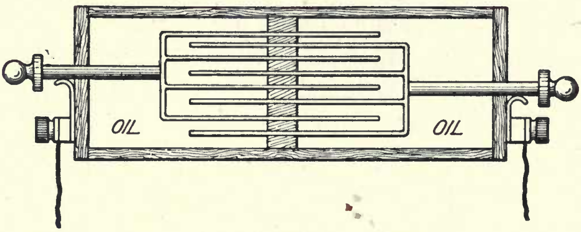


Fig. 30. Adjustable Condenser

condenser varies directly with the square of the potential to which it is charged, it is evident that there exists a definite relation between the dielectric strength of the medium (glass) and the volume per unit of energy which it is desired to store. This is equivalent to saying that a great amount of energy could be stored in a very small condenser if the dielectric could stand an exceedingly high potential. Hence, the object to be attained in the designing of condensers for radiotelegraphy is a maximum energy-storing ability with a minimum of cost, size, and weight of glass. In practice it is better to use a good grade of glass free from lead and other impurities. Oil condensers are sometimes used, constructed of sheets of brass or zinc, and immersed in "transformer oil." Adjustable condensers, made as shown in Fig. 30, are often used for purposes of tuning; their capacity may be varied by withdrawing the plates, thereby reducing the effective area. Braun employed small condensers made of test-tubes covered with tin-foil inside and out for short-distance low-power stations.

Quart or gallon Leyden jars are often employed, lending themselves very well to the requirements.

Tuning Coils. In order to facilitate the tuning, or syntonizing, of the oscillatory circuits included in a system of radiotelegraphy, some apparatus for varying the electrical dimensions of such a circuit is usually employed. These tuning devices consist simply of a variable inductance, or of an adjustable condenser to vary the capacity, or of both embodied in a single piece of apparatus. As the inductance factor lends itself more readily to a simple method of variation, numerous forms of adjustable inductance coils have been devised, the design of which depends upon the circuit they are to be employed with.

Tuning coils for use with the transmitting side of a station are characterized by a comparatively few turns of very heavy wire or metal ribbon wound spirally on an insulated drum or ebonite cylinder. Connection is made at any point on the spiral conductor either by means of flexible connecting cords provided with metallic clips, or by the use of a sliding connection so arranged as to permit of any desired length of the inductive conductor being included in the circuit. Many systems utilize the space within the turns of inductive resistance for the placing of the condensers, thus greatly economizing the room otherwise required for these two portions of the apparatus.

As the receiving circuits usually possess much less capacity than the transmitting circuits, the tuning coils designed for connection therewith have a much larger number of turns. Such coils are generally constructed with several hundred turns of rather fine wire wound on a large bobbin having two sliding contacts so arranged as to include between them any desired number of turns. These coils are made in a great variety of ways.

Spark Gaps. An important element of the transmitting station is the gap, across which the stream of sparks takes place. In a previous chapter attention has been called to the resonator of Hertz and to the metallic balls between which he produced his oscillatory spark. In his book on "Electric Waves" published in English in 1894, he advises that these balls be highly polished. For the small amount of energy used by Hertz this was no doubt advantageous, particularly in the production of short waves; but with the further development of the art it became evident that it was impossible to maintair such surfaces when employing sparks of great volume. The essential condition to be fulfilled is that the discharging surfaces shall maintain a permanent condition and not be burned away and pitted by the rapidly recurring heat of the spark. With the utilization of radiators of high power, and with the employment of transformers capable of charging large capacities, the need of a means for maintaining a constant condition of the spark gap became imperative. Special appliances were devised to prevent the pitting of the balls and their consequent destruction.

Marconi early adopted the Righi oscillator plan of placing the balls in a chamber of oil, or other highly insulative medium, thereby excluding the oxygen of the air from the balls and preventing oxidization. He soon found, however, that the insulating fluid was rapidly decomposed under the influence of the more powerful discharges and abandoned the idea in favor of a "dry" ball system.

Numerous inventors have contrived many so-called multiple-ball exciters, among whom is J. S. Stone, whose oscillator is shown in Fig. 31. R. A. Fessenden has conducted numerous experiments which seem to indicate that there is great advantage to be gained by causing the spark to take place in a compressed-air chamber. This is explained by the fact that the effective potential between the balls is thereby raised without rendering the spark non-oscillatory. Better radiation is possible also, according to Fessenden, and it is undoubtedly a great improvement in reducing the ear-splitting noise of the customary discharge. Various compressed gases have also been used with varying success.

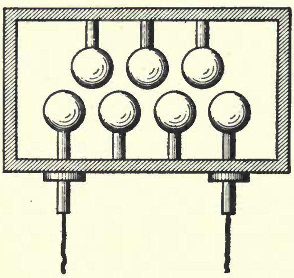


Fig. 31. Multiple-Ball Exciter

Among the various forms of exciter which have more or less successfully fulfilled the requirements, mention must be given to one other fundamental form employed by Marconi. It took advantage of the important fact that though it is exceedingly difficult to create a true alternating arc between two relatively moving surfaces, nevertheless an electric oscillation from a condenser can readily take place even though the movement be exceedingly rapid. Marconi, therefore, devised what is known as the *high-speed disk discharger,* shown in Fig. 32. It would seem that this design of gap possesses many advantages as attested by the extensive employment of it at the trans-Atlantic stations. The illustrations make clear the connections. The apparatus consists of two metallic disks *A* and *B*, revolving at high speed, and a second larger disk at right angles to the axis of the other two and between them, also revolving at high speed. There are thus two gaps where sparks may take place. The closing of the key charges the condensers *C* and *D*, in series between which is connected the condenser *E*, which discharges the energy across either

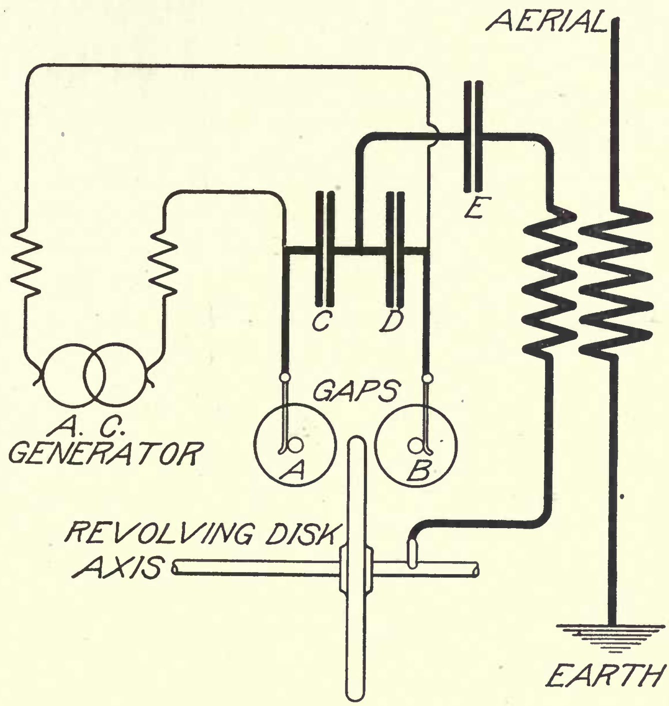


Fig. 32. Diagram of Marconi High-Speed Disk Discharger

gap between the rapidly revolving terminals. Another modification of this device, shown in Fig. 33, is characterized by the fact that it is designed for use with a direct current. The mechanical construction is similar to that of the form previously described, with the exception that the large disk has a row of metallic studs placed equidistantly around its circumference in such a manner as to greatly shorten the length of the air gap between the two revolving terminals when the said studs occupy a position in a line with the plane of their rotation. The office of these studs is to shorten the air gap at predetermined and equal intervals, thus discharging the condensers, which are immediately charged by the direct current. In both forms of the device the arc is prevented by the rapid rotation of the revolving parts. It is claimed that the Marconi dischargers permit of great rapidity of signaling. The last described produces, when run at very high speed, an almost continuous train of oscillations.

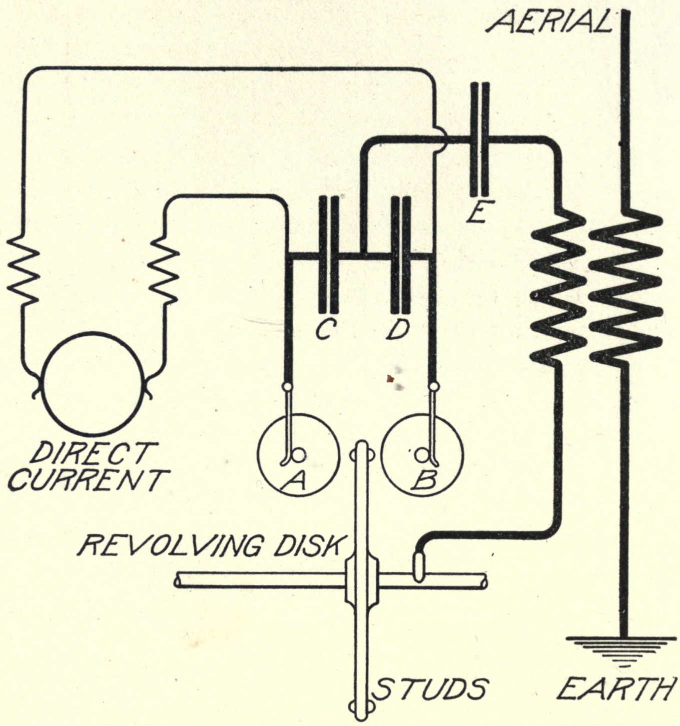


Fig. 33. Disk Discharger for Use with Direct Current

High-Frequency Alternators. It was known at an early date in the history of radiotelegraphy that a much greater efficiency could be achieved if a means were devised for creating a continuous train of undamped oscillations. The Morse dot, which is the minimum signal, was seen to be composed of a considerable number of separate trains of waves, each rapidly damped. Could these "gaps" in the wave train be filled up, the received signal would not only be stronger, but selective signaling would also be greatly facilitated and precise tuning be more easily accomplished. A moment's thought will suffice to convince that a continuous train of undamped oscillations would be the exact equivalent of a continuous alternating current of extremely high frequency; and this opens up the possibility of employing generators which might be connected directly with the aërial, thus doing away with the intermediate condenser and spark gap.

Many attempts have been made to construct generators of sufficiently high frequency, the majority of them having been of the inductor type. An exceedingly small electrical output seems to be the characteristic of all attempts thus far to produce such a machine. Great speed of rotation of the disk armature is required in this type of generator, and as there are limits beyond which it is unsafe to push the rotation, fundamental difficulties arise which have not as yet been surmounted with any degree of commercial success. Fessenden claims to have produced an alternator giving a frequency of 80,000 cycles. The wattage is said to be about 250. The ingenious German inventor, Ernst Ruhmer, has also constructed an alternator of the inductor type having a frequency of 300,000 and an output of but .001 watt; and W. Duddell has succeeded in producing a frequency of 120,000 with somewhat greater power. Until it is possible to greatly increase the output of such machines, their use will be limited to laboratory experiments, or at most to short-distance work in connection with radiotelegraphy. Their development at the present time seems to be in connection with radiotelephony.

The Singing Arc. Much more successful have been the attempts to produce a continuous train of undamped oscillations from a direct current. Elihu Thomson applied, in 1892, for a United States patent on a method intended to effect such a transformation, Fig. 34. A source of direct current is connected to a circuit having a very high inductance, and a spark gap across which is shunted a condenser, and smaller inductance in series. The inventor claims in his patent specifications that the gap, inductance, and capacity can be so adjusted that the condenser is periodically discharged across the gap at frequencies as high as 40,000 per second.

The form that this apparatus has since taken is known by the name of Duddell singing arc, on account of the further developments introduced by him in 1900. Duddell substituted a carbon arc for the gap, and found that such an arrangement produced a clear

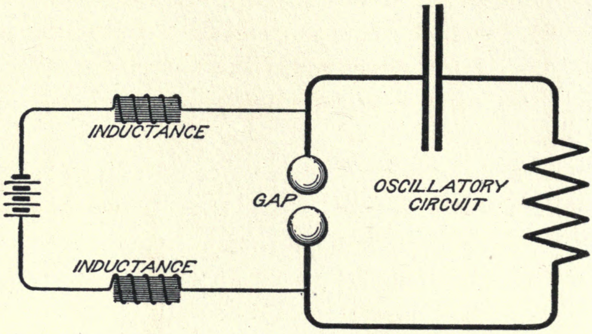


Fig. 34. Thomson Direct-Current Method of Generating Oscillations

musical note plainly audible some distance away, the pitch of the note depending on the value of the capacity and the inductance in the oscillatory circuit—the latter is represented by the heavier lines in Fig. 35. The best effects were obtained by the use of solid rods of

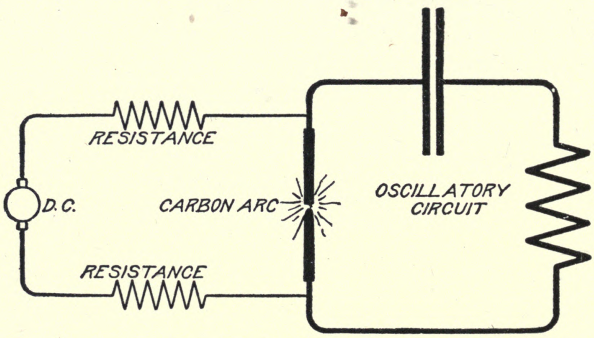


Fig. 35. Duddell Singing Arc

carbon. The resistance of the inductance in the oscillatory circuit must be low—about 1 ohm. Duddell found it difficult to produce oscillations of any considerable power above a frequency of about 10,000; although other experimenters have succeeded in reaching a frequency of 400,000 with small capacity and little energy.

It remained for Valdemar Poulsen of Copenhagen to make the greatest improvement in the direct-current arc method of producing oscillations. Fig. 36 shows Poulsen's arrangement. In the first place, he enclosed the arc in an air-tight chamber filled with coal gas, and used a water-cooled positive electrode with a carbon negative. He also introduced into the chamber the polar projections of two powerful electromagnets in such geometrical relation as to cause the lines of force to pass directly between the electrodes as shown in the diagram. The connecting lines make clear the circuit. The fundamental similarity to Thomson's circuit is apparent. It is possible to produce very powerful undamped oscillations with this apparatus, the frequency of which may, by the proper adjustment of the capacity and the inductance, be made as high as 1,000,000 or more. There is a particular length of arc, called the "active" arc, which gives the best results. Poulsen's device is operable with many other gases besides the one mentioned. The magnets *S* and *N* must be very powerful. 500 volts seems to be a practical voltage for use with this device.

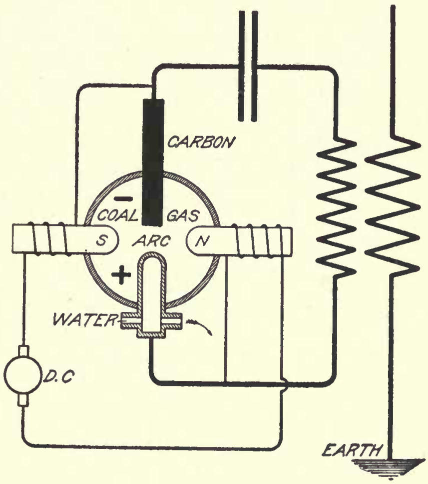


Fig. 36. Poulsen Direct-Current Method of Generating Oscillations

Aërials. The aërials at present used are of many kinds, ranging from the short length of weatherproof wire extending from an upper window to a nail in the chimney, proclaiming the abode of a juvenile experimenter, to those enormous structures taxing the resources of modern engineering in their construction, which achieve trans-Atlantic communication. It was early recognized that the radius of communication was greatly extended by increasing the capacity of the aërial; which fact has led to the employment of multiple-wire antennae. Figs. 37, 38, 39, and 40, show some of the commoner forms, conditions usually determining the choice. It was found by experiment that the capacity of two wires suspended in the air was not twice the capacity of one, nor four wires twice the capacity of two, if such wires were placed near together. The reason, therefore, is apparent why in many of the aërials the individual wires are separated to comparatively great distances.

It is of extreme importance that the upper end of suspended radiator wires should be exceptionally well insulated, and the reason is obvious. Specially designed porcelain or glass insulators are used, having two holes through which the ends of the wires are bound.

Aluminum wire serves excellently for the purpose of antennae when the strain upon it is not too great. Its low tensile strength

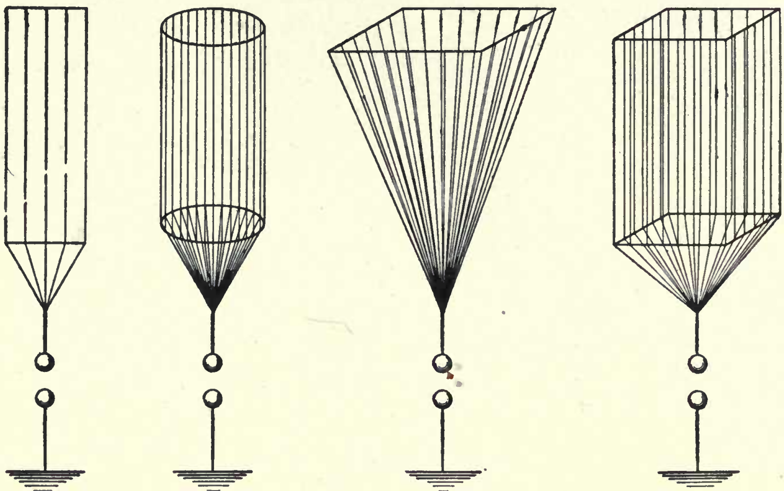


Fig. 37. Fig. 38. Fig. 39. Fig. 40.

Standard Forms of Aërial

precludes its use in some cases. A simple manner of suspending a single-wire experimental aërial is shown in Fig. 41. The mast, or short flag-pole, may be lashed to the tallest object available and the wire carried out of perpendicular a sufficient distance to prevent it from hitting the pole. In army field-equipment, kites or captive balloons are often used to elevate the aërial wire, which is carried wound upon a reel. Many aërials are arranged with a tail block on a cross-tree in order that they may be let down from a high mast for inspection purposes. Such aërials are of the cage variety shown in Fig. 38. An idea of the construction of antennae when designed for use in connection with high-power stations may be gained from Fig. 42.

Directive Antennae. Many efforts have been made to direct the transmission of radiotelegraphic signals to any desired point or locality, but with indifferent success. Early attempts embodied the use of large reflectors behind the oscillator; but the most encouraging results have been accomplished by the use of what are known as *horizontal antennae*, the subject of a patent granted to Marconi and dated 1904. DeForest has also met with some success along this line. The results obtained by these investigators are not formulated well enough as yet to warrant a description of them here.

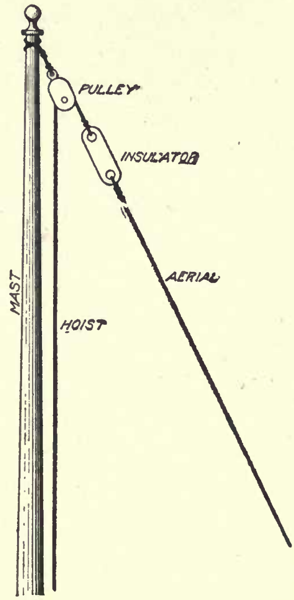


Fig. 41. Single Wire Experimental Aërial

Detectors. The subject of the reception of wave-trains and the transformation of their energy into visual or audible signs through the agency of suitable translating devices will now be taken up and described. It is helpful toward a comprehension of this part of the subject to get clearly in mind the primary effect of a train of waves upon a receiving aërial, namely, the creation of an

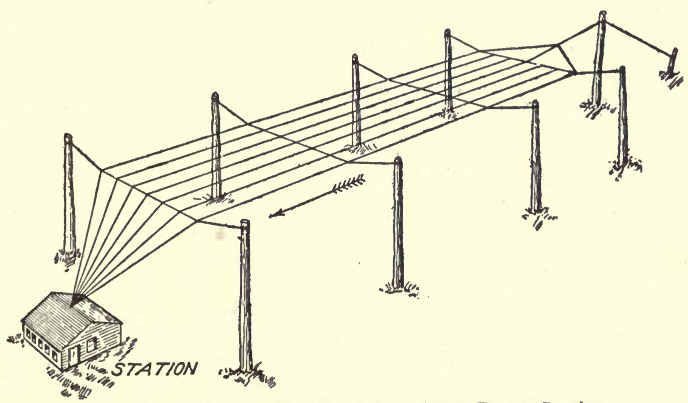


Fig. 42. Antennae Construction for High-Power Station

alternating electromotive force. And the prime function of a receiving device is broadly to detect the presence of a high-frequency alternating current of minute value. Volumes could be written on the history of the various forms of receiving devices which have occupied the attention of the various investigators in this interesting field of experiment. In the present instance attention will be called to those forms only which have proved themselves of practical value.

Wave-detecting devices may be classified for convenience according to the physical principle on which they act, such as thermo-electric, magnetic, electrolytic, chemical, photo-electric, physiological, etc. This course will be followed as far as practicable.

Coherers. Coherers work on the principle of imperfect contact and are called self-restoring and non-restoring according as their sensi-

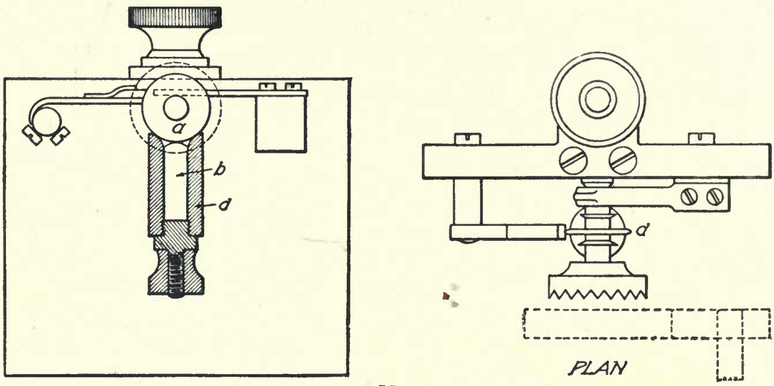


Fig. 43. Lodge-Muirhead Detector

tiveness is automatically reassumed after the passage of a train of waves, or must be superinduced by some external agency. Commercially the coherer has become almost obsolete.

Branly Coherer:—It is unnecessary at this point to give more than passing mention to the Branly coherer, as it has been fully described in a previous chapter. As improved by Lodge and Marconi it performed a very important function in the early days of radio-telegraphy, but has now fallen into disuse.

Lodge-Muirhead Coherer:—An interesting form of contact detector is shown in Fig. 43, devised by Lodge and Muirhead. It consists of a slowly moving steel disk *a* whose sharpened edge is prevented from coming into contact with the small globule of mercury *b* by means of a thin film of oil interposed between the mercury and the steel and contained in the recess *d*. Oscillations passing through the oil cause a breakdown of its high resistance, permitting a translating device to operate by reason of the improved conductivity. Upon cessation of the oscillations, the movement of the disk re-establishes the initial receptivity.

Italian Navy Coherer:—The Marconi Company used with success for a time the so-called "auto-coherer" invented by Signor Castelli, and often referred to as the Italian Navy coherer. The

Fig. 44. Castello "Auto-Coherer"

action is entirely automatic. In Fig. 44, *i* is an iron cylinder separating two globules of mercury; *c* and *c'* are of carbon. Cohesion between the mercury globules and electrodes exists only under the stimulus of the oscillations.

Tantalum-Mercury Coherer:—The tantalum-mercury imperfect-contact detector invented by L. H. Walter is the simplest as well as one of the best of the self-restoring coherers. A small portion of the filament of a tantalum incandescent lamp is connected to a piece of platinum wire for terminal purposes, and the tip of the tantalum is immersed in mercury, which thus forms the other terminal. The whole may be sealed up in a vacuum to avoid oxidization of the mercury. The contact offers very high resistance to a small e. m. f., but falls very low under the influence of the received oscillations. It is rapidly self-restoring. Telephone receivers are often used with this class of detector instead of the Morse relay and recorder, thus allowing the detection of signals from much greater distances owing to the extreme sensitiveness of the Bell instrument to minute differences of current. Such a receiver responds by a buzz to the Morse dash from the distant station.

Valve, or Rectifier, Detectors. One of the difficulties of detecting electric oscillations is the fact that they are of an alternating nature. With the present means at our disposal it cannot be said that we can detect the presence of minute alternating currents with the ease with which we can detect direct currents of equal value. This has led to endeavors to rectify the high-frequency alternations of the received oscillations. Detectors of this type are known as valve, or rectifier, detectors, and one of the simplest means of detecting radiotelegraphic signals is afforded by such devices. To their extreme simplicity is due to a large extent the present number of amateur wireless installations to be seen on all sides. The action of the silicon detector, shown in Fig. 45, is due to the fact that a considerable number of substances in nature possess the property of unilateral conductivity, or the property of conducting electricity freely in only one direction. H. H. C. Dunwoody discovered that carborundum possessed this property to a very marked degree, and would act as a detector if introduced into a receiving circuit in place of a filings coherer. He later observed that no battery was necessary when using a telephone receiver shunted by a small condenser, as shown in Fig. 46. The following substances will all act in place of the carborundum: copper pyrites, iron pyrites, galena, silicon, zinc oxide (perikon), molybdenum sulphide, and titanium oxide. G. W. Pierce has found that the resistance of these substances may be 3,000 times greater in one direction than in the other. The theory of this peculiar action cannot as yet be said to be complete.

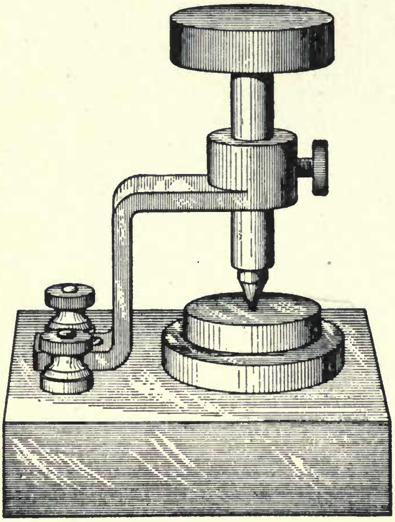


Fig. 45. Silicon Detector

Carborundum, silicon, and perikon seem to be the most satisfactory, particularly silicon, which makes a very sensitive and inexpensive device. Such materials used as detectors of electric waves allow but one-half of each wave to pass, thus giving rise in the telephone to a rapidly pulsating current in one direction to which the telephone can respond. The energy of the oscillations, therefore, directly achieves the audible signal. It has been found, however, that in some cases better results are obtained with a shunted battery cell in the circuit. It is important when using any form of valve detector that excellent connection with the crystal should be maintained at least on one terminal, a deposit of some suitable metal often being employed, thus permitting of a large area of contact. The adjustable contact is preferably pointed and securely held.

Glow-Lamp Detector:—The glow-lamp detector, invented by Prof. J. A. Fleming, was one of the first valve detectors. The theory of its operation may be understood from the inventor's description and with reference to Fig. 47. "An ordinary incandescent lamp with carbon filament has a metal plate included in the glass bulb, or a metal cylinder *C* placed round the filament, the said plate or cylinder being attached to an independent insulated platinum wire *T* sealed through the glass. When the carbon is rendered incandescent by electric current, the space between the filament and the plate, occupied by a highly rarefied gas, possesses a unilateral conductivity, and negative electricity will pass from the incandescent filament to the plate, but not in the opposite direction. This effect depends upon the well-known fact that carbon in a state of high incandescence liberates electrons or negative ions; that is to say, point charges of negative electricity. These electrons, or corpuscles, are constituents of the chemical atom. Hence a carbon filament in an incandescent lamp is discharging from its surface negative electricity, which may even amount to as much as an ampere or even several amperes per square centimeter. If, then, an incandescent lamp made as described has its filament rendered incandescent by a continuous current, and if another circuit is formed outside the lamp connecting the negative terminal of the filament with the insulated metal plate or cylinder in the bulb, and if oscillations are set up in this circuit, negative electricity will be able to move through this circuit from the filament to the plate inside the bulb, but not in the opposite direction."

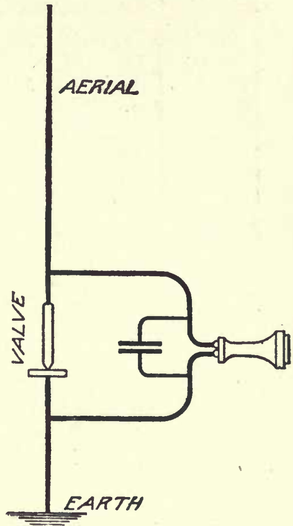


Fig. 46. Diagram of Dunwoody Detector

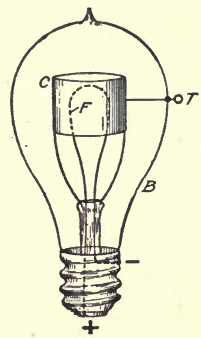


Fig. 47. Fleming Glow-Lamp Detector

It is evident from the foregoing that there are present in the glow-lamp device the essentials of a valve detector. Fig. 48 shows a receiver circuit employed by Marconi making use of the Fleming lamp. Instead of passing the rectified uni-directional impulses directly through the telephone, they are passed around the secondary of a large induction coil in series with a condenser, to the primary of which the telephone receiver is connected. Prof. Fleming is authority for the statement that this arrangement, when suitably adjusted, is "one of the best long-distance receivers for electric waves yet devised."

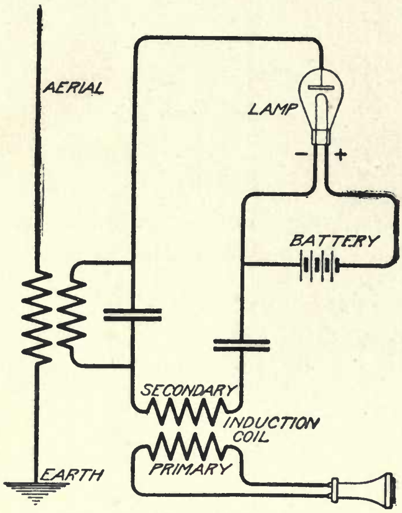


Fig. 48. Marconi Circuit Using Fleming Detector

Audion:—The so-called *audion* of DeForest is a modification of the Fleming detector just described. Fig. 49 shows its connection in a receiving circuit. The lamp used has a low-voltage tantalum filament with two wings, or terminals, sealed in the bulb, as shown. This detector is said to be fairly sensitive, though of short life.

Magnetic Detectors. During the summer of 1902, Marconi was successful in receiving signals sent out from Poldhu on the coast of Cornwall to Flace Bay, Nova Scotia, by means of a remarkably ingenious magnetic receiving device invented by himself and called a *magnetic detector*. Since that time many devices have been patented depending for their operation upon the magnetic effects of the electric oscillations. There has been much discussion relative to the action involved in the Marconi device as well as in other modifications based on the magnetic phenomena

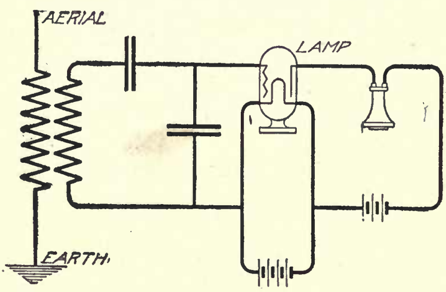


Fig. 49. Receiving Circuit with Audion Detector

associated with oscillatory currents. The explanation advanced by Marconi himself will, therefore, be given here, which in substance is as follows, reference being made to Fig. 50.

The aërial and ground are connected to a few turns of rather heavy wire wound upon a glass tube *T* over which, but insulated from it, is another coil inductively related to the first and connected to the terminals of a telephone receiver. Two strong permanent magnets are placed with like poles together, as indicated. *P* and *P'* are two pulleys carrying on their periphery an endless belt composed of several fine wires of about No. 36 gauge, which are made to pass

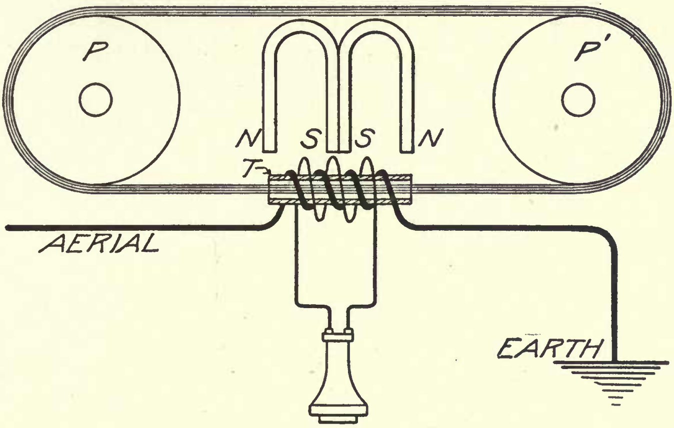


Fig. 50. Diagram of Marconi Magnetic Detector

continually through the axis of the coils by a train of gears not shown. Owing to the hysteresis of the material of the band it tends to retain its magnetism for a short period after it has passed out of the strongest part of the field; but if a train of waves from the aërial is passed through the primary coil to the ground, the effect is to annul the hysteresis and thereby to hasten the demagnetization of the iron wire. This action results in a variation of the flux in the secondary winding, thus inducing electromotive forces in the secondary coil, which make themselves audible in the telephone as a series of sharp ticks. This is said to be one of the most sensitive devices ever made.

A diagrammatic drawing of a magnetic detector, invented by H. Shoemaker, which very closely resembles the early embodiment of the Marconi apparatus is shown in Fig. 51. There have been many variations of the magnetic detector but space will not permit of a description of less important forms.

Thermo-electric Detectors. Comprehended under the head of thermo-electric detectors are those instruments which depend for their action on the heating effects of the oscillatory currents. These

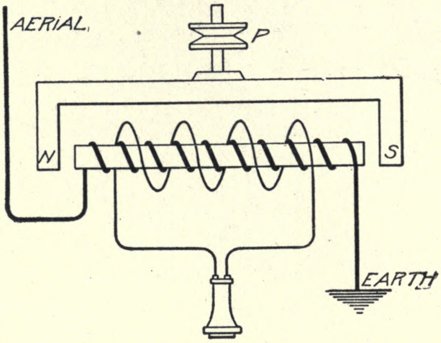


Fig. 51. Shoemaker Magnetic Detector

detectors are especially useful in making quantitative measurements of the amount of energy received under a given condition, and indeed find their greatest utility therein. Fessenden has given great care to his investigations of this form of detector with the result that his so-called "barreter" shown in Fig. 52 is of the same order of sensitiveness as the coherer. It consists of a short piece of exquisitely fine platinum wire connected to suitable terminal wires and the whole enclosed in a vacuum bulb. The temperature rises rapidly under the action of the oscillations, causing an increase in resistance which is indicated by a Wheatstone bridge, in the circuit of which the detector is connected as one of the arms. Attempts have been made to apply the phenomena of the *thermo couple* in this connection, but with only qualified success. It would seem for many reasons that thermo-electrical detectors will not be able to compete with other forms in long-distance work.

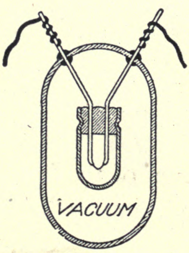


Fig. 52. Fessenden Barreter

Electrolytic Detectors. It remains to take up the class of detectors known as *electrolytic.* DeForest's name is associated with this variety of receiving device, as it was first extensively used by him in a form invented by himself. It consists of a glass tube $\frac{1}{8}$ inch in diameter enclosing conductor plugs after the manner of the Branly coherer. In the interspace is placed a paste composed of rather coarse filings worked up with an equal quantity of oxide of lead in glycerine or vaseline with a trace of water or alcohol. Its resistance increases during the passage of the wave train.

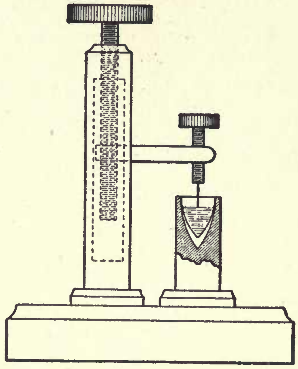


Fig. 53. Liquid Barreter

Fessenden Liquid Barreter:—The most sensitive and practical electrolytic detector is the liquid barreter invented by Fessenden, Fig. 53. It consists essentially of a small containing vessel filled with nitric acid into which projects a platinum wire electrode, which is of extremely small diameter. The apparent resistance of the cell is greatly reduced by the oscillations. The exact nature of the action is not agreed upon by investigators. It was with a refined form of this detector that trans-Atlantic signals were first received from Scotland by the National Electric Company at Brant Rock, Massachusetts.

Hozier-Brown Detector:—The Hozier-Brown system of wireless telegraphy employs a detector classified by some as depending on imperfect contact, but by others as being electrolytic in its action. It consists of a small portion of peroxide of lead held between terminals of lead and platinum, Fig. 54. The lead terminal is much smaller than the other, being a blunt point rendered adjustable by a knurled screw. A two-volt accumulator connected in series gives the best results, according to the inventor.

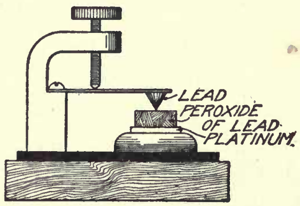


Fig. 54. Hozier-Brown Detector

Electrodynamic Detectors. Mention might be given in passing to the electrodynamic detector devised by Fessenden, although it has never been used extensively. It is designed to operate on the principle that a metallic disk, suspended in a circular coil through which an alternating current is flowing, and at an angle of 45 degrees to the plane of winding of the coil, tends to turn so as to take up a position at right angles to the plane of the coil. This was a fact discovered independently by Elihu Thomson and J. A. Fleming. Fessenden used an extremely light disk hung by a quartz fiber, and he succeeded in obtaining marked deflections of a beam of light reflected from a small mirror fastened to the disk. This device, like the thermo-detector, has been of great service in making quantitative measurements of oscillatory currents.

Auxiliary Apparatus. It would be beyond the scope of the present work to give an extended discussion of the various small devices used in connection with the local receiving circuits, as many of the instruments are not in any way peculiar to radiotelegraphy, being the common adjuncts of wire telegraphy. Mention will only be given to a few points of importance wherein such appliances differ from those commonly employed.

The relay supplied by makers of telegraphic instruments is usually wound with an insufficient number of turns to be efficiently used in connection with a coherer and local battery as a means of actuating a Morse recorder. Rewinding is, therefore, often resorted to. Polarized relays are found to be the best suited to this class of work and should be wound to a very high resistance in connection with all potentially operable detectors. No. 40 wire is often employed.

Sparking at the contacts of the relay is often prevented by the employment of four or five so-called "polarized" cells shunted across the contacts. They are made by inserting a pair of platinum wires through the cover of a small containing vessel partly filled with dilute sulphuric acid, allowing the solution to cover the ends of the electrodes thus formed.

The telephone receivers for use with many forms of detector are much more efficient if wound to a higher resistance than is necessary in the common commercial instrument. Receivers are manufactured in a great variety of forms, only differing from one another in some slight structural modification. The kind known as *operator's double-head receivers* of the watch-case design wound to a resistance of about 500 or 1,000 ohms are well adapted to the requirements of radiotelegraphy.

Dry cells developing an electromotive force, when fresh, of about 1.5 volts are generally used in the local recorder and tapper circuits. One such cell is frequently used in the relay and the coherer circuit.

Measuring Instruments. Perhaps in no department of electrotechnics are the quantitative values of the electrical measurements of more vital importance than in the science of radiotelegraphy. A well-equipped station, therefore, possesses efficient instruments for the measurement of the various electrical factors involved. Besides the common appliances of this nature, such as the voltmeter, ammeter, Wheatstone bridge, etc., it is highly advisable to have the requisite means for making accurate determinations of capacity and inductance. Wave-lengths can be measured by wave-meters, or *cymometers*. These devices are now on the market and are of great utility in a wireless station.

CHAPTER V

SYSTEMS OF RADIOTELEGRAPHY

The history of radiotelegraphy repeats once more the old story that is so often connected with great inventions. The world being possessed of a new scientific principle, many minds in many parts of the world are simultaneously bent upon its practical application, with the result that the fundamental principle finds embodiment in various methods of accomplishing a similar purpose. The startling nature of the discovery of electric waves was bound to give rise to unprecedented activity in the field of experimental investigation; and such experiments as were particularly successful were bound to prompt investigators to seek patent protection on their modifications; and this in turn gave rise to numberless "systems" of radiotelegraphy.

A voluminous list of names could be given of those who have contributed to the advancement of radiotelegraphy in regard to both theory and practice. Among the best-known American investigators are Fessenden, DeForest, Clark, Stone, and Massie. Each of these men has devised a system which bears his name. In England the work has been carried on by men of such unqualified distinction as Lodge, Alexander Muirhead, Fleming, Thomson, and Rutherford. Slaby, Arco, and Braun are the names best known in Germany. The French are represented by Ducretet, Branly, Rochefort, and Tissot, besides other men of lesser fame. We have seen how largely Italy has contributed to the subject; besides Marconi and Righi, mention should be made of Solari, Castelli, and Tommasina. Baviera in Spain, Popoff in Russia, Schafer in Austria, Guarini in Belgium, and Ricaldoni in the Argentine Republic have all invented systems which have been more or less used in their respective countries. The Japanese have also devised a system that successfully stood the test of service in the Russo-Japanese war.

The development of the art in the various countries has been carried on largely by representative investigators, and in many instances the governments have adopted a system exploited by their subjects. The United States government, however, has purchased and experimented with most of the prominent systems offered, and as a result the army and navy equipments comprehend quite a variety of apparatus of different makes.

Telegraphic Codes. Before beginning the description of the more important systems of radiotelegraphy in use at the present time, we will consider the telegraphic codes employed in wireless correspondence. There are three alphabetical codes commonly used at the present time, viz, the Continental, the Morse, and the Navy

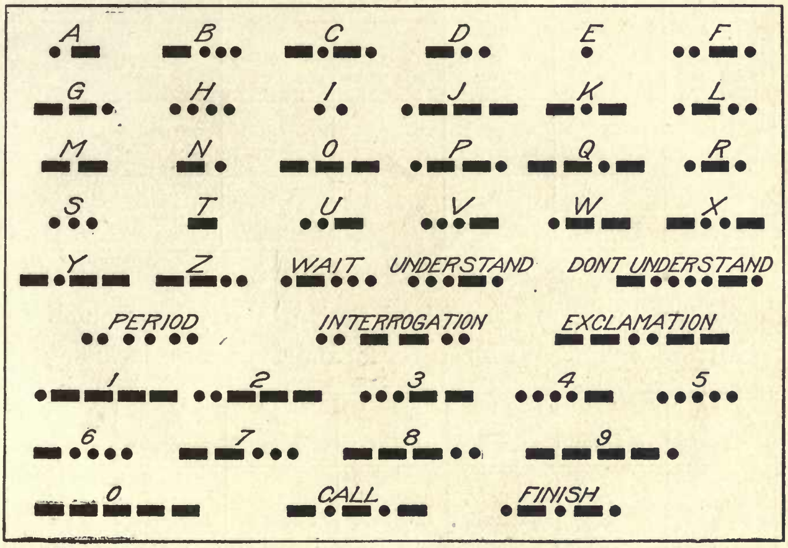


Fig. 55. Continental Code

codes. By far the greatest amount of business is carried on in the Continental code, especially between ships and shore stations. The Morse is more commonly employed for overland service, while the Navy code is confined to naval purposes. Abbreviations of the commoner words are often made use of in transacting the ordinary run of business. The three codes are shown in Figs. 55, 56, and 57.

Marconi System. A detailed description has already been given of the Marconi system as it was about the year 1900. Since then the system has been developed to a remarkable degree so that it stands today a commercial factor of large pretensions. The Marconi stations are scattered in many parts of the globe and are operated in conjunction with all the large telegraph and cable companies.

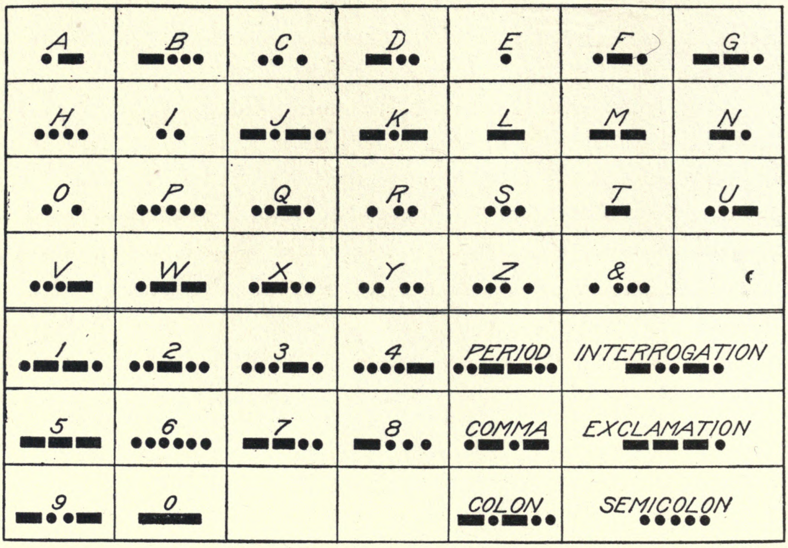


Fig. 56. Morse Code

In addition to the numerous land stations a very large number of vessels are equipped with the Marconi apparatus, including the

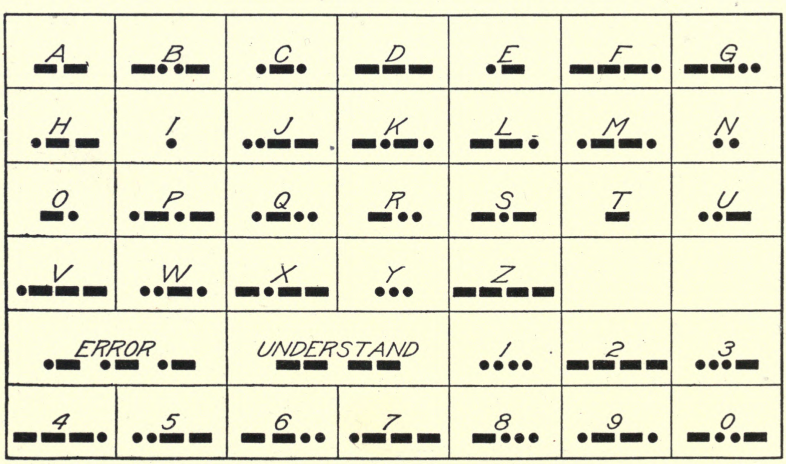


Fig. 57. Navy Code

ocean liners of nearly all the large steamship companies, such as the Cunard line, the Hamburg-American line, the Norddeutscher Lloyd, and many other lines too numerous to mention. Three stations are in operation in China.

For short-distance equipment to be used over a few hundred miles, such, for instance, as is usually installed on Atlantic liners, the Marconi Company employs an induction coil with mechanical break to charge a battery of six to twelve Leyden jars. Two coils and two sets of jars are often supplied in order to readily produce two different wave-lengths. A single spark gap is now used. The Marconi magnetic detector is generally employed, owing to its great simplicity and ease of adjustment. An important improvement evolved by the meeting of practical difficulties is known as the *X-stopper, X* being the name given to certain irregular atmospheric disturbances of an electromagnetic nature which manifest them-

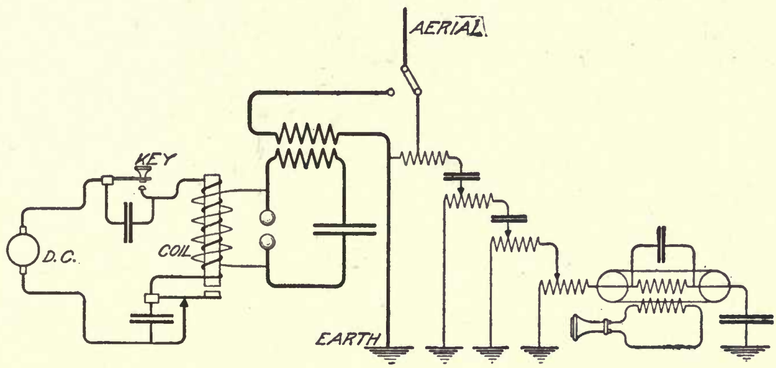


Fig. 58. Complete Marconi Sending and Receiving Circuit

selves as stray signals of sufficient energy to cause confusion in the reception of messages. The means devised by Marconi for overcoming these objectionable interruptions may be seen in diagram in Fig. 58, which shows one form of the complete sending and receiving circuits employed by the Marconi Company. The lower end of the receiving aërial is connected with a plurality of adjustable oscillatory circuits of varying periodicity which terminate in the primary oscillation circuit of the receiving device. The operation of the contrivance depends upon the ability of the first three grounded circuits to perform the function of leading to the ground waves whose frequency does not accord with the periodicity of the system as a whole. It will be noted that the closed type of oscillatory circuit inductively coupled to the aërial as before described is used in the transmitting arrangement of apparatus. The later form of oscillation transformer used at the sending station is designed to provide means for varying the closeness of the inductive couple. This possesses many advantages.

The Marconi Company has equipped several high-power trans-Atlantic stations. The modifications of the short-distance apparatus made necessary for long-distance signaling pertain largely to means for controlling a much larger amount of energy at the transmitting station and the employment of longer wave-lengths. Communication was established the latter part of 1907 between Cape Breton, Nova Scotia, and Clifden, Ireland, by waves 12,000 feet in length generated by means of the Marconi high-speed disk discharger used in conjunction with a condenser of 1.16 microfarads charged to 80,000 volts. Horizontal, or directive, antennae are used with their free ends directed away from each other at the two stations, the horizontal portion being about 1,000 feet long and raised about 200 feet in the air. The Marconi magnetic detector, and also a modification of the Fleming glow-lamp detector, have been used as receptors in this class of work.

An ingenious form of signaling key for use in connection with high-power installations employing alternating current has been patented by the Marconi Company. The fundamental feature of the invention consists in the use of a laminated electromagnet through which the current to be broken is conducted, so placed as to hold the key closed by the attraction of an armature on the key until the current reaches the zero value, at which time the key is allowed to break connection unaccompanied by a spark. The connection may be made and maintained at will, but upon release of the key the circuit is broken at the instant when the current reaches the zero value; the frequency of the alternating current being at least such that this occurs about 100 times per second, the maximum lag of the key behind the movement of the operator's button is inappreciable.

Fessenden System. Fessenden undoubtedly holds a position of first rank among scientific investigators in the field of electric radiation. Moreover, he has proven himself to be an inventor of exceptional originality. His experiments in radiotelegraphy date back to the early days of the art. The National Electric Signaling Company now control the long list of patents resulting from his researches beginning in 1897 and covering a great variety of subjects pertaining to every part of radiotelegraphic equipment as well as to radiotelephony.

The National Electric Signaling Company completed in 1905 two trans-Atlantic stations for communication between Brant Rock, Massachusetts, and Machrihanish, Kintyre, Scotland, a distance of more than 3,000 miles. Successful communication was established on Jan. 3rd, 1906, the detector used being the liquid barreter, already described. An interesting feature of these long-distance stations is the design of the aërial. This is in the form of a vertical steel tube 3 feet in diameter and 415 feet long, resting upon an insulated foundation, and supporting an "umbrella" formed of wires at the top. This structure is held in an erect position by sixteen guys insulated to withstand a voltage of over 150,000. A 25-kilowatt, 60-cycle, boiler-engine alternator supplies the energy.

Fessenden has devoted much time to the problems of selection, interference, and tuning. As a result of his labors in this field, the Fessenden system may be said to represent the highest development in this respect yet achieved.

The National Electric signaling equipment comprises a transmitting device of the direct-coupled aërial variety, characterized by the arrangement of the sending key which, by cutting out a certain amount of inductance in the oscillatory circuit, alters the frequency of the waves emitted—instead of interrupting the primary circuit and causing a cessation of the waves, as in common practice. This requires that a receiving station be tuned with great accuracy, in order to respond to a slight difference of wave-length only, an untuned circuit being thus unable to receive any signals other than a continuous dash. It is claimed that a difference of wave-length occasioned by the operation of the key, amounting to less than one per cent is sufficient to achieve perfect communication. This exceptional freedom from interference is due largely to the employment of what is called an *interference preventer*, diagrammatically represented in Fig. 59, which shows an improved Fessenden receiving circuit. The aërial is connected through a variable inductance to a divided circuit and thence to the ground. In each half of the divided circuit is placed a condenser in series with the primary of an air-core oscillation transformer. The secondary terminals of the transformer are united by a condenser *A*, a signal translating device consisting of the liquid barreter *B*, a potentiometer *C*, and a telephone receiver *D*—all in series. The secondary terminals of the transformers are connected up so as to oppose each other, after the manner of a Hughes induction balance. The aërial and one-half of the divided circuit are tuned to the desired frequency, the other half being momentarily disconnected; then the latter is connected again and the capacity of the condenser *E* is adjusted until the disturbing signals are eradicated. The operation is theoretically as follows: Signals of the proper wave-length pass almost entirely through the side of the divided circuit which is tuned to correspond, while waves of any other frequency pass with equal ease through both sides of the divided circuit, thereby acting differentially on the secondary oscillation circuit because the secondary windings of the oscillation transformers oppose each other. It is said that this arrangement will differentiate between waves differing but one per cent in wave-length.

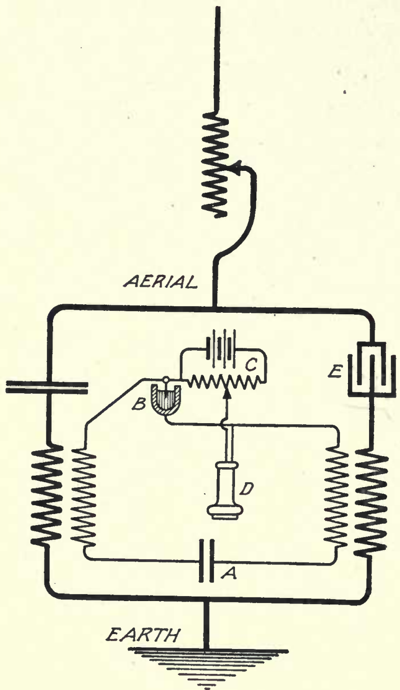


Fig. 59. Fessenden Interference Preventer

Fessenden apparatus is sometimes supplied with a so-called *intensity regulator* for modifying the intensity of radiation without affecting the frequency. This is for use in communicating with nearby stations.

Telefunken System. The system designated by this title is the result of an amalgamation of two formerly separate systems of radiotelegraphy. After patent litigation in the German courts, die Gesellschaft fur Drahtlose Telegraphie (Wireless Telegraph Co.) of

Berlin was formed to take over the conflicting interests represented by the Slaby-Arco system and the Braun-Siemens-Halske system. This company is operating under patents granted to Dr. Rudolph Slaby of Berlin, Count Georg von Arco, and Prof. Ferdinand Braun of the University of Strasburg, each of whom has made important contributions to the subject of space telegraphy. The Telefunken system has been developed to a remarkable degree, due largely no doubt to the powerful influence of the German government, and possesses stations all over the world—numbering more than 500.

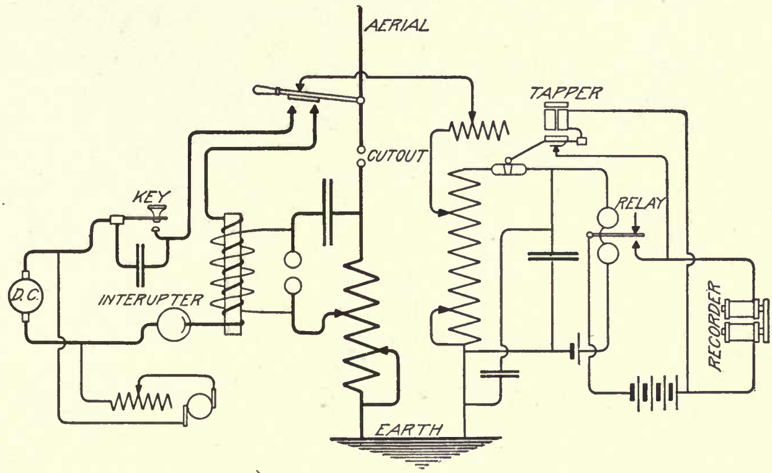


Fig. 60. Circuit Diagram, Telefunken System

Their equipment is sold outright and is noted for excellence of workmanship. The earlier sets of apparatus were furnished with a Morse recorder operated by a coherer of the nickel filings type, but latterly an electrolytic detector and head telephone are furnished as a means of reception. As the recorder and associated apparatus cut down the speed of signaling to a degree that seriously impairs their value for commercial work, the employment of the telephone is becoming almost universal practice. The recording mechanism is, however, preferred by many naval authorities over the telephone, as it eliminates the personal equation of the operator and leaves no possibility of error in the received messages.

A complete wiring diagram of the connections of the Telefunken system is shown in Fig. 60. The aërial is coupled directly onto the closed oscillatory circuit. A small air gap, or cut-out, is located in the transmitting aërial to prevent the received oscillations from flowing through the transmitting circuits. Such a gap offers no hindrance to the high-potential oscillations surging through the radiating circuit of the antennae. Means is shown for adjusting the inductance in the closed circuit of the transmitter, and the inductance between this circuit and the earth.

The Telefunken Company has more recently announced the so-called *singing-spark* system of radiotelegraphy, which is based on the discovery of Wein that exceedingly powerful discharges, possessing useful properties for radiotelegraphy, may be obtained from very short spark gaps. The air gap in this new modification of the Telefunken system is divided between a plurality of copper or silver disks kept apart by rings of mica. This form of oscillation generator is called by the German firm a *quenched spark.* When in operation the device gives forth a clear musical tone, which gives the system its name. The detector employed is of special design and said to be more sensitive than the electrolytic type. It is claimed for the singing-spark system that shorter aërials may be used and that a greater percentage of the energy of the source can be rendered available for radiation; also that the tuning of stations is greatly facilitated.

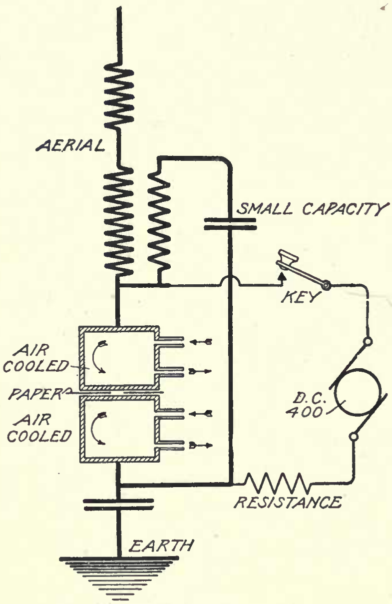


Fig. 61. Von Lepel Oscillation Generator Circuit

Von Lepel System. It has been claimed by the German experimenter, Von Lepel, that he applied the discovery of Wein to practical radiotelegraphy prior to its adoption by the Telefunken people. However this may be, the discovery referred to seems to be of importance, and though this method of producing oscillations is still in the experimental stage, the system of Von Lepel based thereon is of interest. The oscillation generator designed by him is shown in Fig. 61. It consists essentially of two copper-box, air-cooled electrodes about 5 inches in diameter, separated by a thin (.002 inch) disk of paper with a $\frac{1}{2}$-inch hole in the center for the spark. The paper serves to keep the arc from running out to the edge of the electrodes. This paper constantly burns away, but a piece will last about three hours. The connections are indicated in the diagram, which shows a direct-current generator, but an alternating current will also operate the device. *L* and *L′* are inductively coupled inductances, the value of *L′* being very small. The capacity in series with *L′* and bridged across the gap is also very small. A satisfactory explanation accounting for the effects obtained has not yet been put forth. Tests thus far applied to this system have shown advantages not possessed by other systems; but it remains to be seen whether this idea is capable of the extended development it promises.

Lodge-Muirhead System. Reference has already been made to the great service rendered to the art of radiotelegraphy by Sir Oliver Lodge at that early time when its future depended on the elucidation of obscure theoretical points and on those important practical innovations which could alone make possible a commercial development of the idea. Lodge was very early impressed by the fact that periodic currents are amplified under conditions of resonance, and was of the opinion that wireless telegraphy by the early induction method could be facilitated by properly syntonizing the primary and the secondary circuits. He accordingly experimented in this direction and successfully verified his belief. He soon abandoned the notion of inductive telegraphy, however, and joined forces with Dr. Alexander Muirhead, endeavoring to effect wireless telegraphy by means of Hertzian waves. Always keenly aware of the advantages of syntony between the sending and the receiving apparatus, it is not surprising to find that his

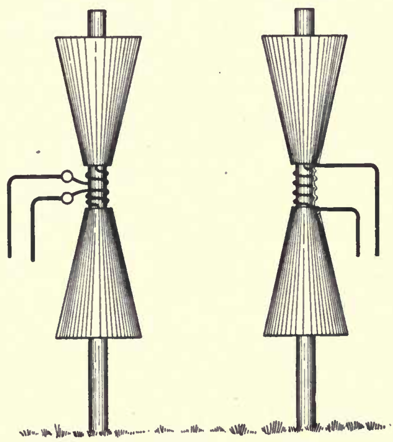


Fig. 62. Lodge Conical Capacity Areas

earliest patent specifications were very copious on this point. To facilitate accurate tuning, large conical capacity areas supported by a suitably insulated frame structure were employed, as shown in Fig. 62. This form of open oscillatory circuit later evolved into the horizontal wire areas now commonly associated with the Lodge-Muirhead system, which is further characterized by being "ungrounded," the lower capacity being in some cases placed several feet above the earth.

One form of a Lodge-Muirhead sending and receiving station is diagrammatically represented in Fig. 63, which makes clear the form of capacity areas more recently adopted. The transmitter is a form of direct-coupled closed oscillatory circuit, and the receiving circuit of the closed inductively coupled type. The auxiliary ap-

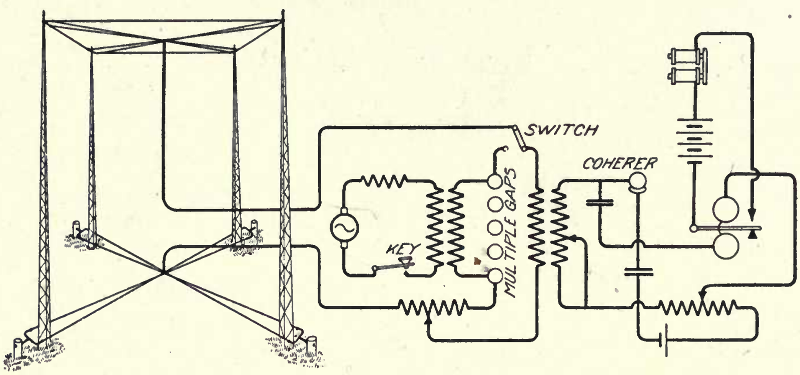


Fig. 63. Lodge-Muirhead Sending and Receiving Circuits

paratus used in conjunction with the Lodge-Muirhead steel-disk coherer previously described is not shown in the drawing. Dr. Muirhead, endeavoring to render the system serviceable in connection with the ordinary forms of telegraphic signaling apparatus, has applied a syphon recorder directly connected with the coherer. A Morse register has also been employed, or a telephone, as occasion suggested. Automatic transmission by means of perforated tape is sometimes used, a perforator being furnished with their equipment.

The Lodge-Muirhead system has never reached the large industrial development achieved by some other systems, notably the Marconi and the Telefunken; but it is, nevertheless, in commercial operation in many parts of the world. Communication was established in 1904 between the Andaman Islands and the mainland of Burma, and has given excellent service since. The distance is slightly over 300 miles. The adverse conditions incident to a tropical climate were here admirably met.

DeForest System. One of the best known American systems is that developed by Dr. Lee DeForest of Chicago. The DeForest interests have many stations located in the eastern States and along the Atlantic seaboard, one of the largest of which, located at Manhattan Beach near New York City, has successfully effected communication with Porto Rico and Colon, Panama, the latter a distance of more than 2,000 miles. A large number of merchant vessels are equipped with this make of apparatus. The United States navy also possesses a number of sets.

DeForest was among the first to employ an alternating-current transformer to charge the requisite capacity. The earlier form of his apparatus included a small motor-generator set delivering current at 500 volts, which was stepped up to 25,000 to 50,000 volts by means of an oil-immersed transformer, the secondary terminals being connected to the aërial and ground with condensers across a gap of the disk type. The receiver circuit used in conjunction with this apparatus was of the untuned kind, the detector being of an electrolytic nature called a "goo" responder, an invention of DeForest and E. H. Smythe. A "needle" anti-coherer of extreme simplicity was used with the earlier equipments, consisting of a light steel needle upheld by a retractile spring against two small aluminum rods. A telephone was employed to respond to the fluctuations of current in a local battery circuit caused by the increased resistance of the needle contacts under the action of the received oscillations. Great simplicity was aimed at in the design of the entire apparatus. No attempt was made to accomplish selection.

Electrolytic and thermo-electric detectors have been the subject of extended investigation by DeForest and his co-workers. As a result thereof a detector was evolved, consisting essentially of a small containing vessel filled with a suitable electrolyte into which projects the tip end of an exceedingly fine platinum wire. This "cell," under the influence of oscillations, exhibits a marked difference in its resistance to a local current. The similarity to the Fessenden liquid barreter is apparent. Much controversy has arisen relative to the theoretical operation of these detectors, DeForest contending that the action was electrolytic, while Fessenden and others have held to the view that the observed effect was due to the thermal action of the oscillations. Whatever the correct explanation may be, the fact remains that the "electrolytic" detector became, in the hands of DeForest, an exceedingly sensitive device and has contributed largely to the success of his system.

DeForest later devised a syntonized system based upon the principle involved in the so-called "Lecher Wires," which reflect waves bearing a definite ratio to the length of such wires. This arrangement, exhibiting anti-nodes of potential and current, possesses de-

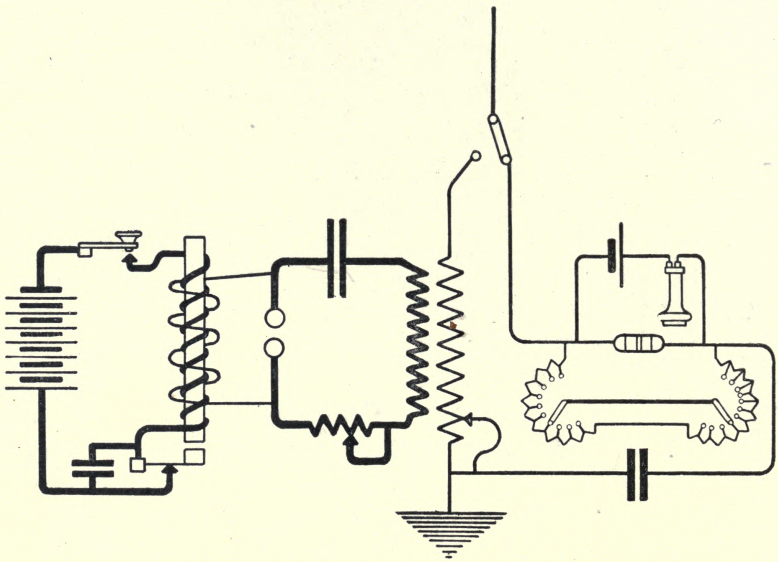


Fig. 64. Clark Sending and Receiving Circuits

cided advantages when applied to the receiving circuit, as it permits a potentially-operable or current-actuated detector to be placed at a point of maximum effectiveness. Possessing also a very definite time-period, this form of circuit was found to lend itself admirably to tuning purposes.

Clark System. The Clark Engineering Company manufactures a form of radiotelegraphic apparatus designed by Thomas E. Clark, which is usually supplied as a portable equipment, contained in oak cases provided with shoulder straps for carrying. Many such sets have been purchased for the Signal Corps of the

United States army, for which service they are especially intended. The aërial wire is preferably raised by means of a kite. The transmitter is of the inductively coupled type, consisting of an induction coil, two one-half gallon Leyden jars, the oscillation transformer, and the necessary auxiliary apparatus, such as secondary batteries, an interrupter, etc. This portion of the equipment is made to be contained in three cases, while the receiving equipment is economically arranged within a fourth oak box covered with canvas. The receptor employed is of the auto-coherer variety, operating under

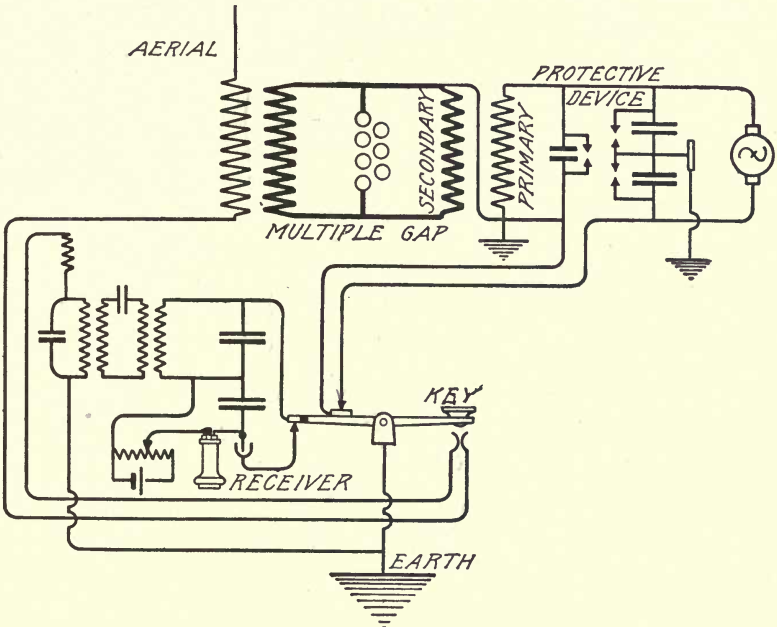


Fig. 65. Stone Sending and Receiving Circuits

the variations of resistance of the imperfect contact between two conducting plugs of steel with a small quantity of carbon granules interposed between them. A head telephone receiver and one dry-battery cell are shunted around the auto-coherer. The complete sending and receiving circuits of the Clark system are shown in Fig. 64. It will be noticed that the system presents nothing of novelty beyond the fact of its admirable adaptability to the requirements of a portable equipment. It can be readily packed on the back of a transport mule, or carried by men in a military campaign.

Stone System. Another American system, which is curiously enough little referred to, is the Stone system, invented by J. S. Stone, who has been granted nearly one hundred patents in this country alone, besides their equivalents in European countries. His specifications cover the widest possible range of subjects pertaining to radiotelegraphy and proclaim him to be the possessor of an extraordinary understanding of the more recondite problems connected with the science. Several of his patents cover the inductive coupling of aërials, something after the manner of the Braun-Marconi method. It is

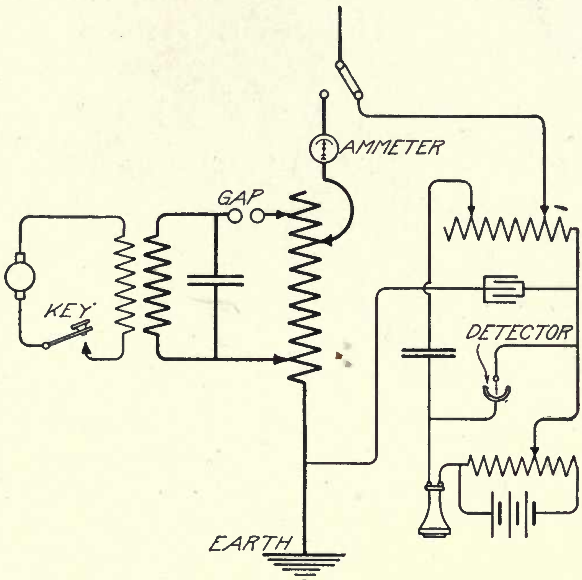


Fig. 66. Massie Sending and Receiving Circuits

difficult to believe that any large proportion of the specifications have ever been tried out in practice; in which case they may represent but "anticipatory" patents. One of the Stone arrangements for the sending and receiving stations is shown in Fig. 65, which embodies features of interest particularly from the viewpoint of the "wireless" operator. Reference is made to the multiple function of the sending key which allows an operator to be "broken in upon" while sending, by reason of the fact that the receiving circuit is broken by the depression of the key but instantly closed upon release. The aërial is inductively coupled to the closed oscillatory circuit containing a multiple-spark gap. Various forms of detectors have been used by Stone, especially electrolytic and thermal devices. In one of his patent applications he describes a thermopile of platinum and gold for use as a detector. The Stone system has never been widely exploited although such equipments are occasionally used in this country and doubtless may be found elsewhere.

Massie System. Walter W. Massie of Providence, R. I., has developed a system of radiotelegraphy which bears his name. While the system has never been exploited on a large scale, numerous sets of apparatus have been purchased by the United States government, and many private concerns find use for this make of apparatus. Massie is well known among the amateur wireless experimenters as the inventor of an exceedingly simple detector of the imperfect contact type, which has rendered many a home-made outfit at least operative where a more complicated receptor would have been prohibitive. The device goes under the name of the *oscillaphone,* and consists simply of a common sewing needle placed carefully across two sharpened carbon edges. A small horseshoe magnet is sometimes located under the needle in order to exercise a slight attraction and maintain good connection. In the Massie equipments supplied for long-distance use, an electrolytic detector is employed. The Massie circuits are shown in Fig. 66. The aërial is direct-coupled.

Poulsen System. A remarkable system due to the genius of Valdemar Poulsen of Copenhagen has of late years attracted great attention, as it undoubtedly marks a decided advance in the art. Poulsen has accomplished by means of a modification in the Duddell arc a method of creating an almost continuous train of undamped oscillations resulting in an equivalent train of electric waves. The ability to generate such a persistent train of waves offers great advantages in the syntonization of stations and in the problem of selective signaling. As before mentioned, the Poulsen system is characterized by the employment of hydrogen under pressure as the surrounding medium for the arc. The receiving device used is the invention of Pederson, and a very full description of it may be obtained by referring to the *Electrician* for Nov. 16, 1906.

Other Systems and Inventors. Numerous other systems of radiotelegraphy have been exploited in various countries, but space will not permit of a detailed description of them here. The patent files of every government contain numberless specifications pertaining to the art; indeed, it is doubtful if any other improvement in electrical communication has called forth in so short a time a more voluminous patent literature.

The *Rochefort-Tissot system* in France has met with considerable success. Perhaps the most distinctive feature of this system is the form of induction coil employed, called a "unipolar transformer." The equipments are manufactured by Ducretet, the French instrument maker.

In Belgium the *Guarini system* has been installed in various localities with moderate success. The inventor has great faith in the possibility of relaying radiotelegraphic messages to accomplish long-distance transmission. He has devised a relay for such purposes, which seems to promise good results.

The Russian government has experimented with several systems, but the *Popoff system* is now almost exclusively used. Considerable interest attaches to this system on account of its historical importance. As early as 1895, Prof. Popoff communicated to the Physico-Chemical Society of St. Petersburg the details of a device employed by him for graphically registering atmospheric disturbances of an electrical nature by means of a coherer introduced between an elevated "exploring rod" and the ground. A relay and tapper were also employed, the former serving to operate a Richards register. It is thought by many that sufficient credit is not given Popoff for these innovations.

Sir H. M. Hozier and S. G. Brown in England have developed a system bearing their names, which differs little from the other systems, with the exception of the detector and method of directly connecting the same to a syphon recorder. The Hozier-Brown detector has been described elsewhere.

A system of selective signaling which seems to promise well, is that named after the inventor, Anders Bull. Resonance is not employed as a selective agency; instead, the receiver is designed to respond only to a group of wave-trains which are separated by certain unequal and predetermined intervals of time. The mechanism effecting the transmission of such properly timed wave groups is called the *dispenser*, and the companion device at the receiving end, the function of which is to translate the wave groups into printed

Morse characters, is called the *collector*. Tests conducted by the United States navy with this system were highly satisfactory as regards secrecy and freedom from atmospheric disturbances. The complicated nature of the apparatus will possibly prohibit the extensive use of this system, although it possesses advantages not even theoretically possible by resonance alone.

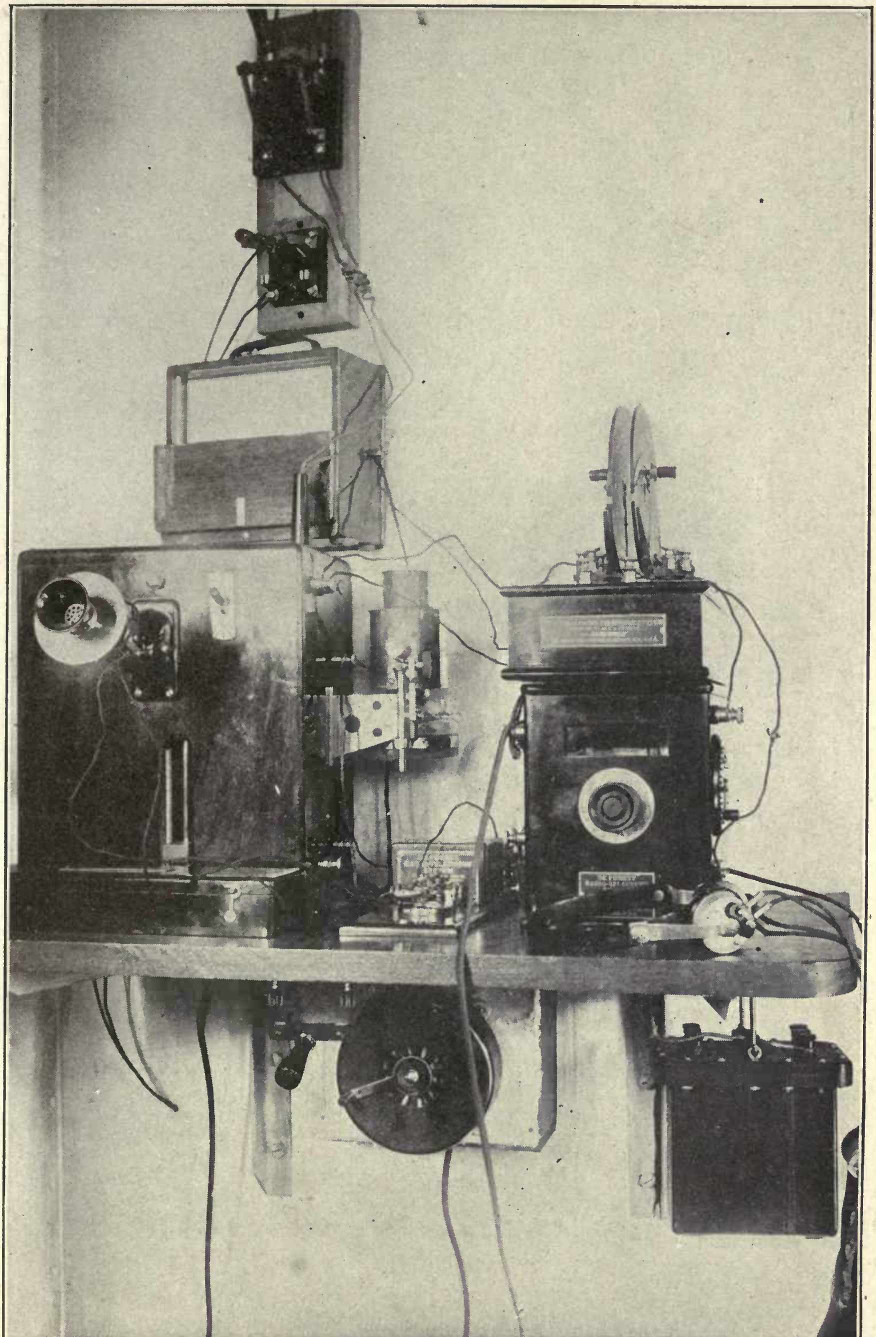
Conclusion. During the twenty years or so since Hertz made his famous discovery of electric waves, radiotelegraphy has made many substantial advances toward the goal of perfection; and it stands today a conspicuous and brilliant example among the many resources which Science has contributed to modern civilization. Its uses are many and important. To mention its life-saving power alone is to secure for it a high claim to consideration. Its success in this regard has been spectacular in more than one instance; and it is not too much to say that radiotelegraphy has saved hundreds of lives since the "wireless" installation of ships has become prevalent. To travel on the ocean with a "wireless" equipment on board, knowing that in case of peril the assistance of vessels within a radius of hundreds of miles can be instantly summoned, adds not a little to the comfort and security of the passenger. Radiotelegraphy may indeed be said to have struck a vital blow to the terrors of the sea. The sea, it would seem, has become the chosen sphere of wireless telegraphy, since it fills a want never supplied before. Formerly ocean-bound vessels were isolated from the world for days at a time; but now they can communicate with land or with other ships at almost any point in their course, some of the large ocean liners keeping in such close touch with events that they publish daily bulletins giving the world's latest news.

Another startling achievement of radiotelegraphy has been its success in effecting trans-Atlantic communication. Messages are sent between Europe and America across a void of air and water some 3,000 miles in extent. And they are not mere test messages, but regular press telegrams such as might be sent by cable. Here radiotelegraphy has become the direct rival of the old method of wire transmission. Whether the one will ever supersede the other is a question open to debate. The probabilities seem to be in favor of wireless, especially if the present rate of progress continues; but, for the present at least, there is room for both methods.

Wireless telegraphy promises to be of great service in times of war; in fact, all the leading nations have equipped their armies and navies with radiotelegraphic apparatus. Battleships will have a facility of communication never before possible, and land forces will be equally subserved. Heretofore, one of the first moves of a belligerent force was to cut the enemy's telegraph wires; but to cut off an electric wave will not be such an easy matter. The Japanese constantly made use of wireless telegraphy in the late war with Russia. The Japanese have their own method of effecting radiotelegraphic communication, the details of which are kept secret; but that it works successfully, they have well demonstrated.

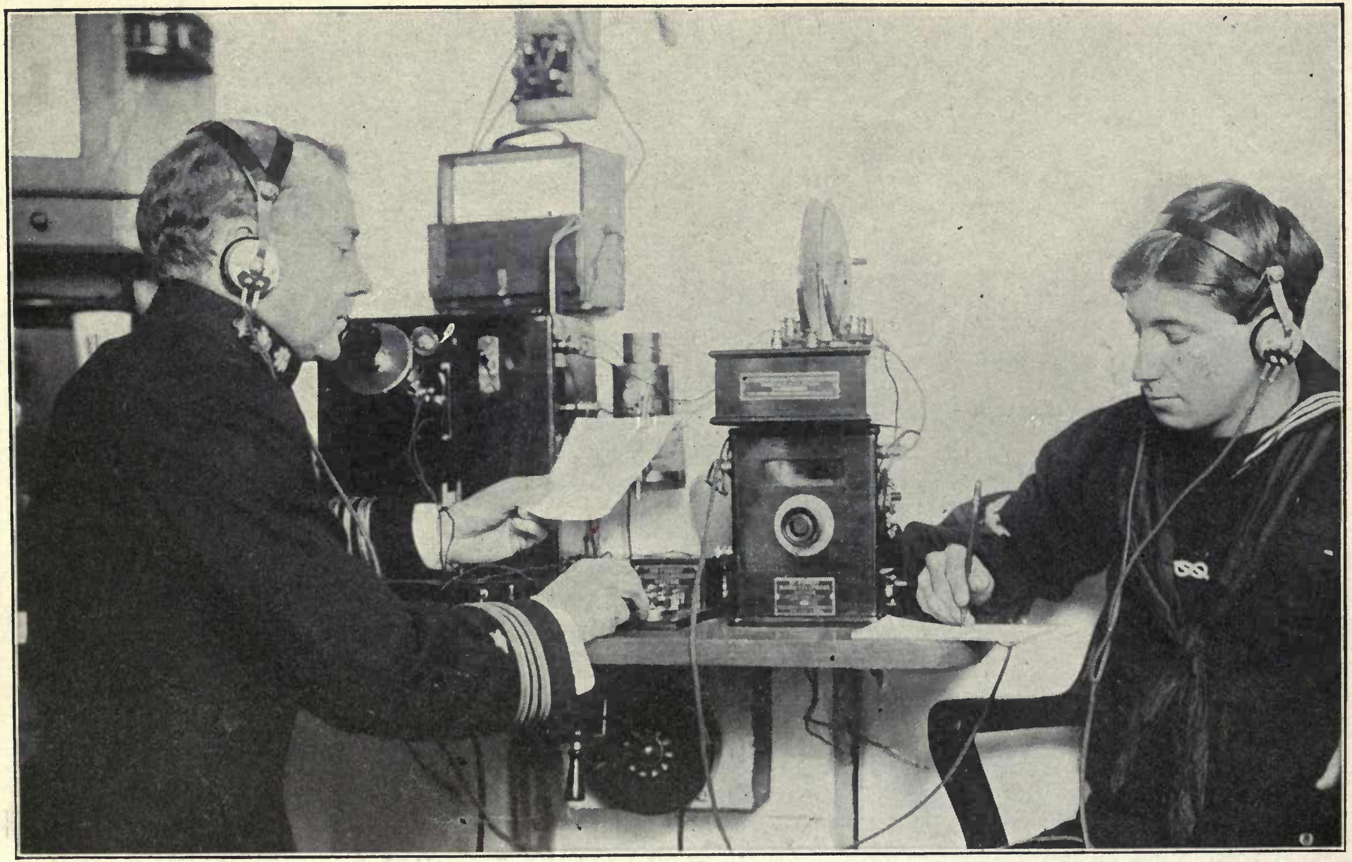
Concerning the utility of radiotelegraphy for communicating across land areas, much that is favorable and promising can be recorded; but there is still something to be desired with respect to ease and certainty of operation. The progress thus far made has brought to light many problems which await solution and recorded many phenomena relative to transmission over long distances, especially over land, which cannot as yet be accounted for or controlled. The screening effect of intervening mountains and cliffs exercises a marked difference in the energy of the received signals; long stretches of exceptionally dry ground seem to have the same effect. This probably accounts for the fact that the greatest distances to which signaling has been carried have been over salt water. Signals seem to be more easily effected at night than in daylight; so marked is this effect that communication carried on with perfect success at night has often been permanently interrupted by the advent of daylight only to be resumed the following night. J. J. Thomson has put forward a possible explanation of this, but space forbids its inclusion here. Again, certain conditions of the atmosphere seem to render but comparatively small energy necessary in the accomplishment of long distances at times.

Thus radiotelegraphy, like all forms of telegraphy, as well as telephony, has its limitations and unsolved problems; but, judging by past achievements, it is not well to dogmatize too emphatically as to the finality of these limits.



THE FIRST SET OF WIRELESS TELEPHONE INSTRUMENTS FOR THE UNITED STATES NAVY

Installed on the Flagship "Connecticut." The "Audion" Receiver with Tuning Device on the Top at Right, the Transmitter on the Left.



SENDING A FIVE-MILE WIRELESS TELEPHONE MESSAGE ON THE FLAGSHIP "CONNECTICUT"
Staff Officer Sending and Assistant Receiving a Distant Message.

WIRELESS TELEPHONY

Wireless telephony is not so new—almost unborn, indeed—as is generally supposed. Like its companion art, wireless telegraphy, it began its existence well back in the nineteenth century. Its inception is contemporaneous with that of wire telephony, for Alexander Graham Bell was the originator of both. It is a singular coincidence that Bell, the inventor of the telephone, and Morse, the reputed inventor of the telegraph, should each have been among the first to accomplish their respective modes of communication wirelessly. The history of wireless telephony follows very closely that of wireless telegraphy. The extreme sensitiveness of the telephone receiver to small variations of current very naturally suggested its employment as a receiving device in connection with the inductive and conductive methods of wireless telegraphy, and attempts were made at an early date to accomplish the transmission of articulate speech by these same means. The results obtained however, were very meager; the inherent difficulties characterizing these methods proved to be even greater with the application of telephone principles, due to the diminution of energy made necessary by the nature of the process. As in the case of wireless telegraphy, the solution of the problem lay in the application of the method of electric radiation.

Bell's Radiophone. One of the earliest attempts at radiotelephony was not of an electrical nature, judging by the usual appearances, but depended on the thermal effect of a variable beam of light directed upon bits of burnt cork enclosed in a small glass tube to which was connected a rubber tube to be inserted in the ear of a listener. This device is shown in Fig. 1. The light from a convenient source was reflected from a thin silvered diaphragm and caused to fall upon the burnt cork. When this diaphragm was set into vibration through the agency of the voice, the light reflected therefrom was subjected to a corresponding variation of intensity, and, being directed upon the blackened cork, produced therein minute changes of volume due to the variations of temperature;

and such changes produced air-waves which were manifested in the form of sound and audible within the tube. This simple device, invented by Alexander Graham Bell, was called by him a *radiophone.* He later greatly improved the apparatus by substituting selenium as the means of reception, the peculiar electrical property of which substance was then first attracting attention.

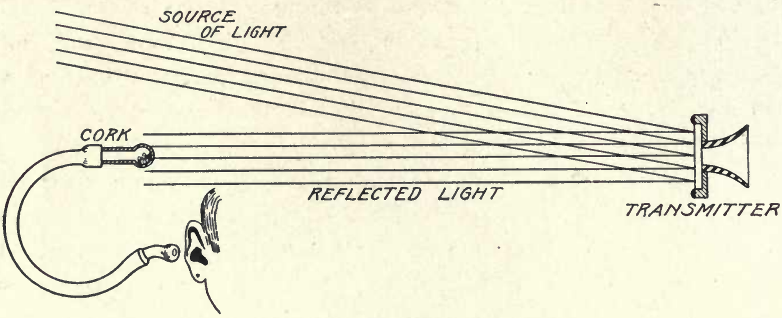


Fig. 1. Bell's Radiophone

Selenium Cell. In 1873, Willoughby Smith discovered that the resistance of metallic selenium was greatly reduced by exposure to light. The light from a small gas burner was found to exercise a marked influence on the conductivity of short rods of selenium used as resistances in a series of cable tests then in progress. The discovery caused widespread interest in the scientific world. Among the many men attracted by this peculiar property of selenium was Prof. Bell, who, in conjunction with Sumner Tainter, succeeded in producing the first useful so-called "selenium cell." This device consists essentially of selenium spread over the surface presented by the edges of alternate disks of metal separated by thin sheets of mica after the manner of a condenser, thereby greatly enlarging the area of contact between the selenium and the electrodes formed by the alternate disks. By connecting such a cell in series with a battery and telephone receiver, the current passing through the circuit is largely dependent upon the degree of conductivity possessed by the selenium cell, which in turn depends upon the amount of light falling thereon. Any variation of the light directed upon the cell is, therefore, capable of causing a corresponding variation of the current flowing through the receiver, with the result that such variations become audible therein.

Bell's Photophone. In 1878 Bell put forward a most ingenious application of the selenium cell for the purposes of radiotelephony, which he called a *photophone.* The arrangement of apparatus is shown in Fig. 2. The selenium cell *C* is placed in the focus of a parabolic reflector *R* and is thus interposed in the path of the rays reflected by the mirrored surface of a diaphragm *D* from any suitable source of light *S*. The resistance of the selenium cell was approximately 1,200 ohms in darkness, and about half that when fully illuminated. The mode of speech-transmission is so similar to that of the radiophone that further description is not necessary.

The photophone, as proposed by Bell, may be made to transmit speech perfectly over short distances, but it is obviously limited by reason of the inefficient means employed to effect the variation of the intensity of a source of light. As the employment

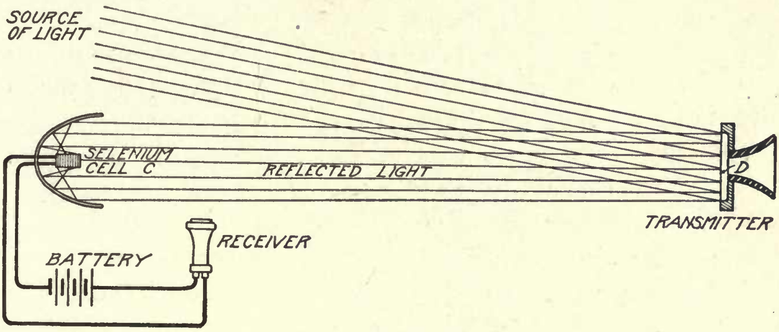


Fig. 2. Bell's Photophone

of the device for distances relatively long necessitated the use of powerful sources of light and adequate means for controlling the same, the invention remained but a beautiful laboratory experiment until the discovery of the speaking arc by Simon in 1897 opened up the possibility of future development.

"Light Telephony." Prof. H. T. Simon of the Physical Institute of the University of Erlangen discovered, toward the end of the year 1897, that a direct-current arc may be made to give forth musical tones and even speech by superimposing a telephonic voice current upon the arc current. This discovery suggested the possibility of using Simon's arc as a transmitting arrangement for the Bell photophone. With this end in view, numerous experiments were carried on, principally in Germany, aiming to increase the efficiency of the apparatus when operated in conjunction with powerful search-lights, and also to develop the selenium cell to a point of greater sensitiveness. Wireless telephonic communication by this means has become known as *light telephony,* and has reached its highest development in the hands of that most ingenious German investigator, Ernst Ruhmer. The German navy has several vessels equipped with the Ruhmer apparatus for intercommunication. It is said that a distance of twenty miles is, under favorable weather conditions, the limit of operativeness with this form of radiotelephony. The use of the system is necessarily restricted to open spaces, and dependent upon clear atmosphere.

Telephony by Means of Hertzian Waves. The success achieved by Marconi in telegraphing without wires inspired many investigators to apply the Hertzian-wave method to the problem of telephony. As early as 1897 various workers became imbued with the idea and, as a result, a number of systems of radiotelephony have grown up contemporaneously with those of radiotelegraphy. It cannot be said, however, that the results accomplished by the early experimenters in this field gave more than a promise of future usefulness for this method of communication, the distances covered being extremely small in proportion to the complexity of the apparatus involved. In many instances, however, the inventors of such systems had a clear perception of the fundamental requirements, and felt confident that the development of the art on its practical side would ultimately make possible a successful application of their theories.

The principal difficulty encountered in the application of Hertzian waves to the problems of telephony was found at the start to reside in the transmitting portion of the apparatus. The receiving end offered no great obstacle, since it was known at an early date that many of the detectors used in connection with radiotelegraphy would prove suitable for the reception of speech—providing that a means could be discovered to effect the emission of wave-trains whose energy should vary in accordance with the vibrations of the human voice. The fundamental problem of radiotelephony is practically the same as that met with in ordinary wire telephony—*to cause a* *distant diaphragm to repeat sympathetically the vibrations of a diaphragm against which the energy of the sounds to be transmitted is directed.* In both cases the efficiency of the various transformations of energy involved in the process is of prime importance. The current-carrying capacity of the carbon transmitter places a limit on the amount of energy possible to utilize telephonically. This restriction is felt to a marked degree when the device is associated with the necessarily large amount of energy required for Hertzian-wave radiation over any considerable distance. In view of the foregoing, it is not surprising to find that early experiments in radiotelephony were directed almost exclusively toward a solution of the problem of an efficient transmitting apparatus.

Many attempts were made to accomplish this end by placing the ordinary microphone transmitter in the primary of an induction coil, thus serving the purpose of an interrupter, as exemplified in Dolbear's early wireless telegraph system. Such experiments only sufficed to show that nothing was to be gained in this way, largely by reason of the before-mentioned inherent limitations of the telephone transmitter. The problem was then attacked in another manner, viz, by endeavoring to modify telephonically a train of waves of a constant intermittency radiating from a continuously operating source of oscillations, such, for instance, as a simple radiotelegraphic transmitter without a primary signaling key. Though this method allowed a much greater amount of energy to be utilized, it soon became evident that a grave difficulty was presented due to the nature of the radiations from such an arrangement. The train of waves thus generated is not continuous, but consists of intermittent wave-trains separated by short periods of time during which no radiation takes place. These breaks in the continuity of the train are often of greater duration than the individual oscillations due to one complete discharge of the condenser; they consequently produce in the telephone receiver a continuous buzz which seriously interferes with the audibility of the received voice vibrations. As the timbre of the human voice depends upon overtones and upper harmonies of a frequency of from 5,000 to 8,000 or more, the pauses between oscillation trains also interfere with clear articulation whenever their frequency drops much below 10,000 per second. At frequencies of from 20,000 to 50,000, however, this feature ceases to be a hindrance. The success of the method of telephonically varying the energy emitted from a continuously operating source of radiation was seen, therefore, to depend upon the possibility of producing more perfectly sustained oscillations of high frequency. The means for creating oscillations that are undamped and practically continuous, may be considered the greatest problem of radiotelephony relative to transmission. At the present time there are two methods of accomplishing such persistent radiations, viz, by employing the high-frequency alternator, or by using some form of the oscillating arc. The last-named method has been developed, under the ministrations of Valdemar Poulsen, to a degree of efficiency that promises to place radiotelephony on a commercial basis. The alternator method has been persistently favored by Prof. R. A. Fessenden, who has accomplished some remarkable results. Both methods have their staunch advocates, each possessing its own peculiar advantages as well as limitations.

Nature of a High-Frequency Telephone Current. The foregoing paragraphs have indicated briefly the general theory upon which the

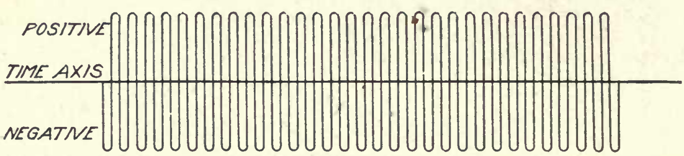


Fig. 3. Diagram Representing High-Frequency Current

most successful systems of radiotelephony have been developed. It remains to consider in more detail the nature of the action involved when a uniform flow of undamped oscillations is modified by the variations of a voice current.

It is convenient for a ready understanding of the matter to first consider the case of a high-frequency alternator supplying a constant alternating current of a periodicity somewhat above human audibility—say 50,000 cycles per second. Supposing such a current to be flowing through a variable resistance such as a telephone transmitter, the effect of an increase of the resistance thereof manifests itself by a lessening of the amplitude of each individual half-wave of current; while, conversely, a decrease of the resistance manifests itself by an amplification of the current half-waves. When, therefore, the resistance is made to vary with great rapidity, as when the diaphragm of the transmitter is thrown into vibration by sound, the effect upon the alternating current flowing therein is to produce a corresponding change in the maxii um value of each half-wave.

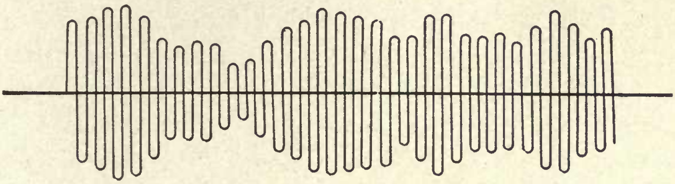


Fig. 4. Diagram Representing Variations of Amplitude

As the energy of each half-wave may be represented by its amplitude, it is evident that an alternating current varying in this manner exhibits a wave-form of energy equivalent in many respects to a direct current similarly modified. Figs. 3 and 4 illustrate this idea, Fig. 3 representing the steady alternating current permitted by the normal resistance of a transmitter; and Fig. 4 showing the alterations of amplitude thereof occasioned by the variations of resistance in the said transmitter. It will be noticed that the maximum instantaneous values may be greater than normal, as well as less, due to the fact that the resistance of a transmitter when spoken into varies between limits above and below its resistance when at rest. Some idea of the complexity of the action taking place under the conditions of actual practice may be had by referring to the wave-form shown in Fig. 5, which represents the current curve, or oscillagram, of a

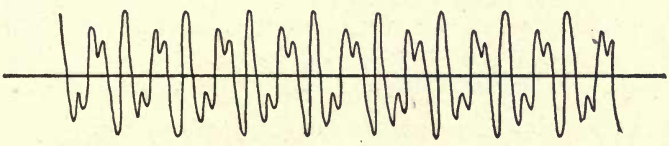


Fig. 5. Oscillagram of a Telephone Current

telephone current produced by the vowel, long ō, spoken into the transmitter. In forming a mental conception of the wave-form resulting from the superimposing of a telephonic voice current upon a high-frequency oscillating current, the enormous difference in their respective periodicities must be borne in mind.

In the case of an oscillation generating arrangement which does not produce a perfectly sustained train of electric waves but a series of partially damped wave-trains separated by slight breaks of continuity, the essential condition for success in connection with radio-telephonic work is that the interruptions shall not take place at an audible frequency. It is highly probable that the direct-current arc method of creating oscillations does not produce an absolutely continuous train of waves, as is the case with a high-frequency alternator, but, on the contrary, is made up of a great number of groups of almost undamped oscillations separated by an interval of time, very small even in comparison with the duration of each group.

Oscillation Generators. An account has already been given, in the pages devoted to Radiotelegraphy, of the attempts which have been made to construct high-frequency alternators for use in the production of continuous, undamped oscillations, and some description given of such machines. Reference has also been made to the development of the direct-current arc method of producing a similar result. In the present instance it is not deemed necessary to dwell on these subjects further than to give some notion of the particular devices constructed for use in connection with the most successful systems of radiotelephony, and to mention those modifications of the arc method which have been found to give the best results in this field of use.

Undoubtedly the most successful high-frequency alternators have been those constructed by Prof. Fessenden for use in his extensive experiments in radiotelephony carried on at the Brant Rock (Mass.) Station of the National Electric Signaling Company. This inventor has devised several such machines, one of them having an output of 2 kilowatts operating at 80,000 cycles, and a voltage of 225 volts. This machine was of the double armature type with 300 teeth on each, direct-coupled to a DeLeval turbine. A similar generator designed for use on shipboard and run by a turbine is capable of developing 3 kilowatts at a frequency of about 100,000 cycles. Fessenden has also designed a 10-kilowatt machine of a periodicity of 100,000 per second. The problem of properly designing such generating units and constructing them on a commercial basis cannot as yet be said to be satisfactorily solved; it is generally felt, however, that the solution of the problem will be effected at no distant date, at which time this method of producing the requisite oscillations for electric-wave communication will supersede in many instances the more complicated and less constant methods now in use.

There are in use at the present time various arrangements of the direct-current arc employed as a means of creating alternating currents of great frequency, all of which depend for their operation upon the principle of the Duddell arc but differing in the details of application. One of the earliest and most successful of these is due to Poulsen, who achieves extremely high-frequency oscillations of great energy by causing the arc to take place between copper and carbon electrodes enclosed in a chamber containing hydrocarbon gas. In order to increase the energy of radiation, Poulsen later employed several arcs in series. This is known as the multiple-arc system, and has been developed to a high degree by die Gesellschaft fur Drahtlose Telegraphie of Berlin.

Telephonic Control of Oscillations. Radiotelephony figuratively substitutes in place of the metallic line of ordinary telephone practice a continuous stream of electric waves of approximately uniform strength. By varying from instant to instant the energy of this stream of waves in accordance with the variations of air-pressure acting against a transmitting diaphragm, a transference of such energy-variations is effected between two stations. By the employment of suitable translating devices, the energy-vibrations of the wave-stream may be made to undergo a transformation resulting in the movement of a second diaphragm which exactly duplicates the vibrations of the first, and the variations of air-pressure occasioned thereby complete the cycle of energy-transformations from sound to sound.

It is to be noted in connection with the foregoing analysis that it is not the entire amount of energy of the flow of waves between stations that is available for transformation into sound at the receiving end, but only the energy represented by the *variations* of this flow of waves. Thus the problem of telephonically controlling a large amount of energy for efficient radiotelephonic transmission is to effect, by means of the energy of the voice vibrations, a maximum percentage of variation in the energy radiated. With the methods employed at the present time there are reasons for believing that this percentage does not greatly exceed 5 to 8 per cent of the total energy.

In this respect radiotelephony differs very widely from radiotelegraphy, for with the latter the entire energy of radiation is available to the limit of our ability to detect it. Some of the inventors claim a greater percentage of efficiency for their respective systems of radiotelephony. Fessenden has devised an improved form of transmitter which he states produces much better results.

There are several ways of modifying the electric oscillations set up in a transmitting arrangement for the purposes of radiotelephony. The method generally employed involves the use of some form of carbon transmitter whereby the variations of its resistance under the influence of the energy of the voice are made to vary the oscillatory current directly, or a local-battery circuit similarly affected is inductively associated with the oscillatory circuit. Variations in the emitted wave-train may also be accomplished by the use of a condenser transmitter formed by a thin metallic diaphragm separated from a metallic plate by a thin layer of air acting as dielectric, the vibrations of said diaphragm producing variations of capacity between the two surfaces. This variable capacity is used to throw the aërial in and out of tune. The inductance of an oscillatory circuit may also be made to vary by means of the voice and produce a like result. One of the earliest suggestions relating to the telephonic control of the energy of oscillations was made by an Italian, Lonardi, who, in 1897, proposed that the spark balls of a Righi oscillator connected to a source of constant potential be made to vibrate by the voice, thereby altering the length of the spark gap and causing the oscillator to be charged to greater or lesser potentials, and thus varying the energy of the emitted waves.

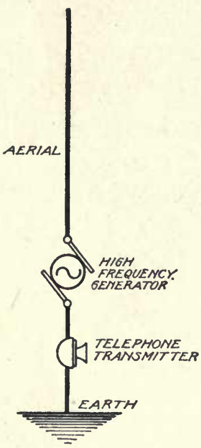


Fig. 6. A Form of Fessenden Circuit

Transmitting Circuits. One of the simplest and earliest circuits patented for use in connection with radiotelephony is shown in Fig. 6. It is due to Fessenden, and consists of a high-frequency alternator connected in series with an aërial, a telephone transmitter, and the ground. The time-period of the radiating circuit thus formed is adjusted to the periodicity of the dynamo.

The patent application on this arrangement was filed in 1901 at a time when it is generally believed that the creation of electric waves necessitated an abrupt release of energy, as exhibited by the discharge of a condenser. In experiments carried on with this arrangement in 1906, a distance of about ten miles was covered, the generator running at 10,000 revolutions per minute and developing 50 watts at 80,000 cycles per second. The resistance of the armature was about 6 ohms. An electrolytic cell was used for a detector.

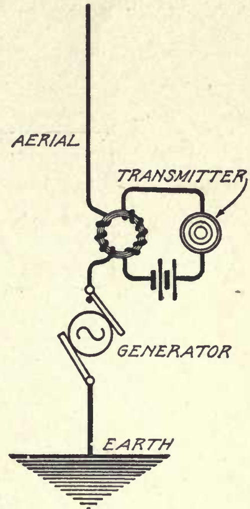


Fig. 7. Transmitter Inductively Associated with Aërial

Another method of effecting the telephonic variation of an oscillatory system is shown in Fig. 7. The aërial is connected to the secondary of a small transformer, the primary winding of the same being included in a local-battery transmitter circuit.

An arrangement for use with the arc form of oscillation generator is shown in Fig. 8. Direct current for the arc is supplied to the terminals of the closed oscillating circuit through the secondary of

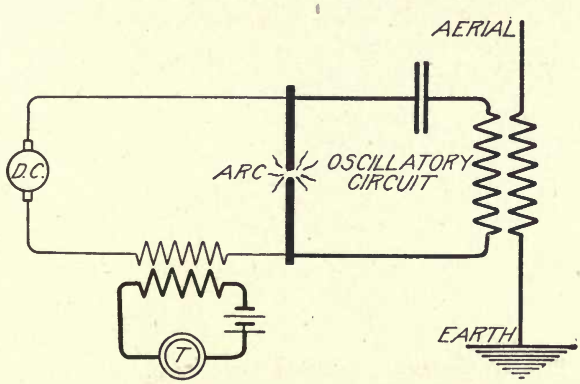


Fig 8. Transmitter Associated with the Supply Circuit

a transformer, the primary circuit of which contains a carbon transmitter and local battery. The fluctuations of intensity of the oscillations may be effected in a manner diagrammatically shown in

Fig. 9, where the inductive method of superimposing the telephone current from a local circuit is applied directly to the closed oscillatory circuit. Inductances *I* and *I'* inserted in the supply mains

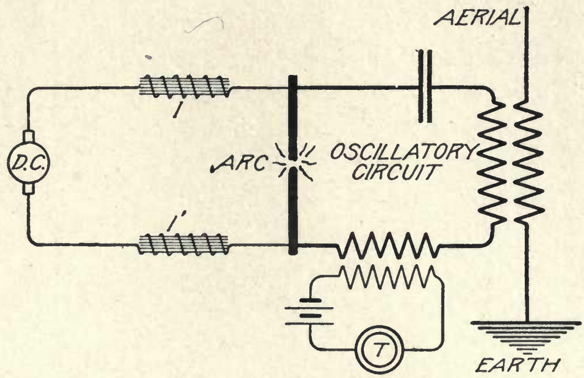


Fig. 9. Transmitter Inductively Associated with the Closed Oscillatory Circuit

prevent the voice current from passing around through the source of supply.

In Fig. 10 is shown still another method of locating the variable-resistance member, viz, by shunting the secondary of the oscillation

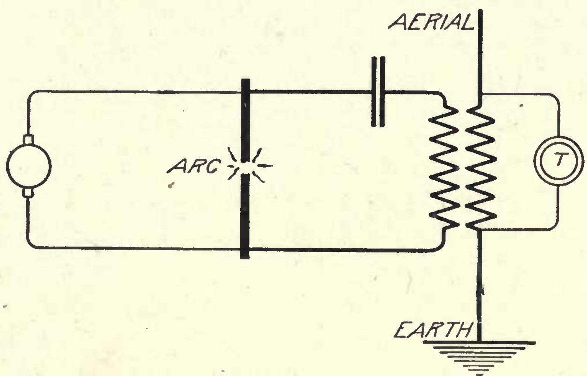


Fig. 10. Transmitter Shunted across the Aërial Inductance

transformer employed in connection with an inductively coupled aërial. The telephone transmitter may also be used with a directly coupled aërial by causing it to vary the effective turns of a portion of the inductance included in the open radiating circuit, as in Fig. 11.

From the circuits here given, it is evident that the conditions essential to telephony are fulfilled when the transmitter is so placed as to produce by its action a change of the electrical properties of the radiating aërial; and experience has shown that this may be accomplished with the microphonic, or carbon, transmitter in a variety of ways, many of which seem to operate with equally good effect. The condenser, or variable-capacity, transmitter is effectively operative only in conjunction with the oscillatory portions of the sending circuit, usually as a shunt. One method of placing this form

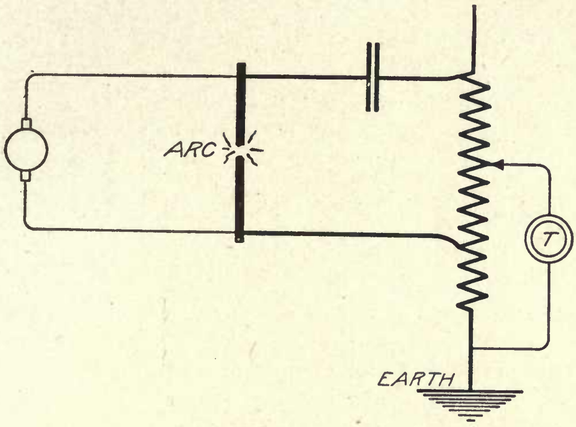


Fig. 11. Transmitter Shunted across a Portion of the Aërial Inductance

of transmitter is shown in Fig. 12, which arrangement has been employed by Fessenden.

As before remarked, the small current-carrying capacity of the microphonic transmitter has proved to be a great obstacle to the rapid development of the art of radiotelephony as a commercial proposition; and it may be said that until an efficient means is devised for overcoming this difficulty, and thereby greatly increasing the percentage of variation in the intensity of the oscillations, or the equivalent thereof, the sphere of usefulness for this form of wireless communication will be much restricted. Many attempts have been made to effect this improvement by connecting several transmitters in multiple to be acted on by a common mouthpiece. Various so-called telephonic repeaters have also been devised purporting to accomplish an increase in the amplitude of the telephonic current Such devices, however, have not proved to be a satisfactory solution of the problem, although Fessenden claims to be able to effect a decided amplification with an instrument of the latter character designed by himself. This ingenious investigator has undoubtedly constructed an instrument more nearly fulfilling the requirements of a transmitter adapted to this class of work than any heretofore presented. It is called by him a "trough" transmitter, and is said to be able to carry continuously more than 10 amperes. The electrodes are water-jacketed The amount of variation in a current of this magnitude, produced by the action of the voice, is of course the important factor. The results accomplished by the "trough" transmitter indicate a decided gain over the form commonly employed. Further radical improvements in transmitter design may be confidently expected from the numerous experimenters whose inventive ability is now being brought to bear on the problem.

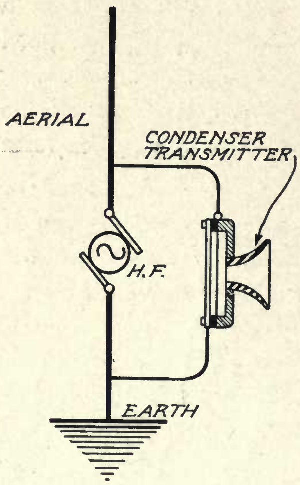


Fig. 12. Condenser Transmitter

Receiving Arrangements. For purposes of radiotelephony the detectors depending upon mere potential for their operation, such as the early forms of coherer, are practically useless. The essential characteristic which a detector suitable for this class of work must possess is that it shall not only respond to the received oscillations, but that it shall be affected to a certain extent in proportion to the amplitude of such oscillations. In short, radiotelephony requires a form of detector which is quantitative, that is, one which will respond to the varying integral value of the oscillating current. Such devices as the thermo-electric, electrolytic, ionized gas, and crystal-valve detectors are all of this type, and may be used for the reception of speech when properly connected with a telephone receiver. This quantitative function may be elucidated by considering the action of a thermo-electric detector properly associated with a tuned receiving circuit. If a continuous train of undamped waves falls upon the aërial, their effect on the detector is to increase its resistance by raising its temperature, and thereby decrease the amount of current flowing through the telephone receiver. As long as the flow of such waves remains constant, their heating effect upon the fine platinum wire of the detector, and consequently its resistance, remains constant, and no sound is heard in the receiver. If, however, the wave-train which strikes the aërial be of a fluctuating nature, due to the vibrations of the distant telephone transmitter, the variations of amplitude of the received oscillations will cause a corresponding variation in their heating effect on the platinum wire, accompanied by like variations in its resistance, whereupon the current flowing through the telephone receiver will be similarly varied, with the result that the diaphragm is thrown into vibrations exactly imitating the movement of the transmitting diaphragm.

There have been previously described under the head of radiotelegraphic detectors almost all the devices used for a similar purpose in connection with radiotelephony. In view thereof it is not thought necessary to devote more space to the subject here, further than to call attention to a form of telephone receiver invented by Fessenden and called by him a "heterodyne" receiver, a most ingenious application of the Bell instrument to the purposes of space telephony. The device consists of two small coils of wire, one of which is wound upon a stationary laminated core composed of very fine soft-iron wires; the second coil, held in close proximity to, and co-axial with, the first, is attached to the center of a thin mica diaphragm. A high-frequency current from a local source is maintained through the stationary coil. The other coil, arranged to vibrate with the diaphragm, is connected in the receiving oscillation circuit, as shown in Fig. 13. The periodicity of the local alternating current is adjusted to approximately the same frequency as the received waves, thereby creating a mechanical force exerted be-

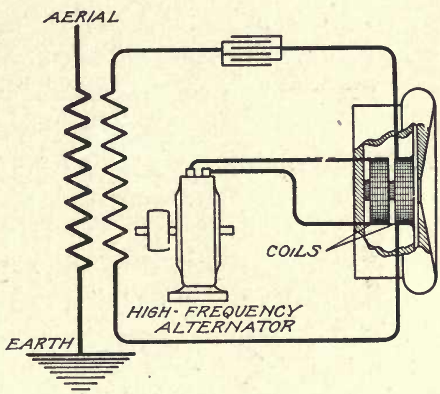


Fig. 13. Heterodyne Receiver Circuit

tween the two coils—a force which varies with every fluctuation of the intensity of the received oscillations, and results in vibrations of the mica diaphragm corresponding to those of the distant transmitter. When this device is used as a detector in connection with radiotelegraphy, the frequency of the local source of current is purposely made to be slightly different from the frequency of the received oscillations; under which condition the physical phenomenon known as "beats" is engendered. This is due to the fact that at certain equal intervals the two wave-form currents agree in phase and reinforce each other, while at times midway between two such successive agreements they are opposite in phase and tend to neutralize each other. These intervals of maximum reinforcement occurring at an audible frequency produce in the receiver a musical note of a duration depending upon the length of the Morse dot or dash. By means of this simple process, it is, therefore, possible to produce audible tones by the interaction of two alternating currents whose respective frequencies are far above audibility. The heterodyne receiver is almost entirely unaffected by atmospheric disturbances, and seems to offer exceptional possibilities in connection with multiplex transmission, as well as selective communication.

Two=Way Transmission. In wire telephony simultaneous talking and listening is possible by reason of the simple nature of the circuits and because of the comparatively small amount of energy involved in telephonic transmission. Radiotelephony presents in this regard difficulties which tax to the utmost present inventive ability. Without special appliances it is of course necessary after talking to throw over a listening key or switch in order to receive the reply. The introduction of this manual operation, while not of a nature to greatly detract from the usefulness of this method of communication, interferes to an appreciable extent with that ease of operation we are accustomed to associate with the telephone, and destroys the illusion of the actual presence of the person spoken to. It cannot well be expected in an art so young that minor details of this nature should have been thoroughly perfected. Arrangements for simultaneous talking and listening have already been put forward, and some have met with more or less practical success. Fessenden has patented several such devices—one involves the use of a commutator which connects the transmitter and receiver to the aërial in very rapid alternation; another and a more practicable method is called by him the "balance" method, and consists in the application of the "bridge" together with a "differential" arrangement often employed in duplex telegraphy, the complete circuit requiring a "phantom," or artificial, aërial. The detector is unresponsive to the powerful oscillations emanating from the same station, but sensitive to the oscillations from the distant station. This "balance" method materially cuts down the loudness of the received sounds.

Radiotelephonic "calling" is accomplished by radiotelegraphic methods. A coherer associated with a local battery and relay is sometimes employed to ring an electric call bell. In such cases it is necessary to provide means for cutting out the coherer and relay during conversation. Under conditions where it is impractical to achieve the operation of a relay, it becomes necessary to keep an operator on duty "listening in."

Systems of Radiotelephony. Radiotelephony undoubtedly possesses many advantages over radiotelegraphy, not the least of which is the fact that a skilled operator is not required to translate the dot-and-dash signals. The transmission of intelligence is more direct and expeditious, and in times of emergency this might become an advantage of great importance. No form of communication is so satisfying as that of speech. It is due to this fact, perhaps, that ordinary wire telephony stands today superior to the older art of telegraphy in point of development. The future may record a similarly greater development of radiotelephony than will be accorded to its companion art; but at the present time it cannot be said to compare with radiotelegraphy as regards efficiency and simplicity of apparatus. Its weak points are known and understood, however, and every effort is being made to remove the obstacles that stand in the way of a more efficient utilization of the means employed.

While still susceptible of great improvement, and in many cases requiring a multiplicity of complicated apparatus, there are a number of radiotelephonic systems which have been exploited in the various countries, many of which are in regular service. Nearly all of the large navies of the world are supplied with equipment for intercommunication between the different vessels of a fleet. Among the most successful systems may be mentioned the Telefunken and Ruhmer systems in Germany, the Poulsen system in Denmark, the Marjorana system in Italy, and in America the systems developed by Fessenden, DeForest, and Collins. Many other systems are known, but they exist in a more or less imperfect state of development.

Telefunken System. Die Gesellschaft fur Drahtlose Telegraphie of Berlin has put forward one of the most thoroughly developed systems of radiotelephony in commercial operation at the present time. It is generally known as the *Telefunken system,* which is the name applied to the radiotelegraphic system operated by the same company.

The Telefunken radiotelephonic system is of the oscillating-arc type. The arrangement of circuits is shown in Fig. 14. Six or

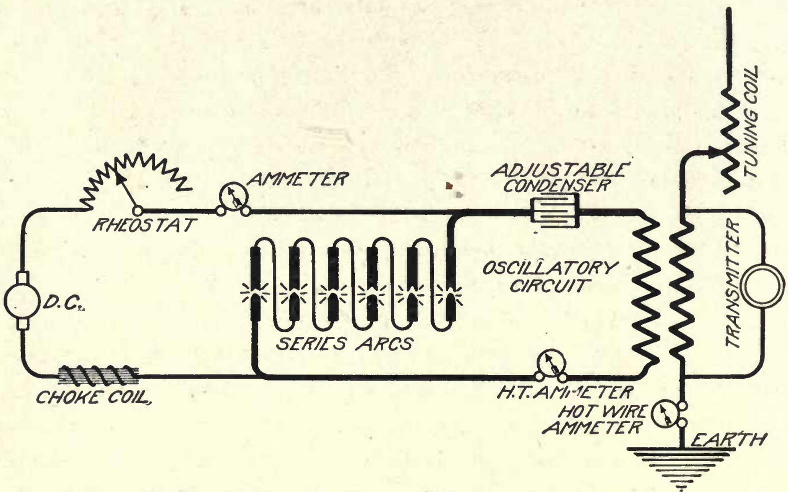


Fig. 14. Transmitter Circuit of the Telefunken System

twelve electric arcs, connected in series and shunted by an inductance and capacity, form the source of the high-frequency oscillations. The energy supplied to this portion of the circuit is derived from a direct-current source of 220 or 440 volts (if the latter, 12 arcs in series are used) connected through a rheostat, an ammeter, and a choke coil. The choke coil is used to prevent the oscillatory current from passing through the dynamo. A hot-wire ammeter is included in the oscillatory circuit, and another between the aërial and the ground, used for tuning purposes. When the circuits are in exact resonance, these instruments give a maximum reading, thus affording a very convenient means of ascertaining if the system is in proper adjustment at any time. An adjustable condenser is provided in the oscillatory circuit, and a variable inductance in the aërial, to facilitate tuning. It will be noted that the carbon transmitter is associated with the aërial as a shunt around the secondary of the oscillation transformer. An ordinary transmitter is used and, in practice, means are provided for opening the transmitter circuit while calling, and at other times when it is desired to protect the transmitter from the detrimental effects of continued exposure to the heavy current.

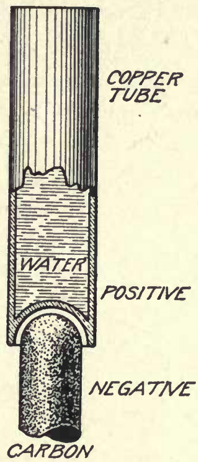


Fig. 15. Telefunken Electrodes

The electrodes employed for the arcs in this system possess features of interest. The positive member is formed by a copper tube about 2½ inches in diameter and 8 inches long closed at the bottom by a concave piece of the same material. The internal cavity is filled with water, thus serving to keep the metal cool. Fig. 15, which shows the Telefunken electrodes, represents the positive member as partially cut away in order to make clear the construction. The negative electrode is of carbon 1½ inches in diameter, set well up in the concave portion of the positive electrode, but separated therefrom by a gap of about ⅛ inch. The arc formed between these two members tends to maintain the uniformity of the gap. It is claimed that the consumption of carbon is only about 1 inch in nearly 300 hours, and that the copper electrode is not appreciably affected by the arc. The water is changed as often as required, according to the time it is subjected to the heat of the arc, or by reason of evaporation. Means are provided for the adjustment of each individual arc, and for the simultaneous striking of all. The frequency usually achieved by this method is approximately 375,000 cycles per second. The equipments are rated something under one kilowatt for connection with 220 volts.

The receiving arrangement used with this system is of the simplest kind, consisting of a detector (electrolytic or thermo-electric) and telephone directly coupled to the aërial, such as are commonly employed with radiotelegraphy. The entire apparatus is very compact, requiring but little space, and may be conveniently placed on a small table. A distance of 25 to 45 miles may be very well covered with the Telefunken sets such as are supplied for use on shipboard, and equipments of greater power may be had. Simultaneous talking and receiving is not provided for in this system.

Ruhmer System. The system due to Ernst Ruhmer, the German investigator, well known for his extensive work in connection with the development of "light telephony" and for his researches

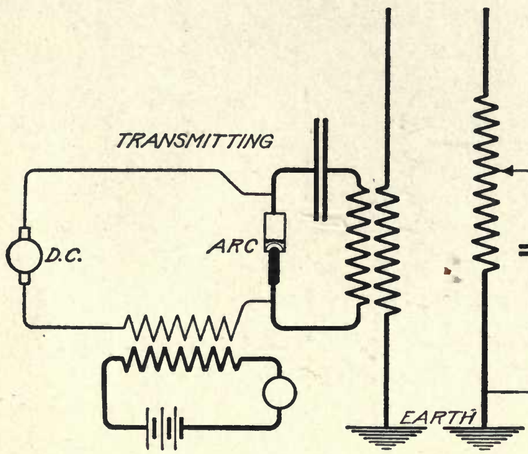


Fig. 16. Circuits of Ruhmer System

into the properties of selenium, is characterized by the use of an oscillatory arc burning in hydrogen or other suitable gas. The Ruhmer circuits are shown in Fig. 16. A local-battery transmitter circuit is employed to superimpose, by means of an induction coil, the voice current upon the supply terminals of the oscillatory portion of the arrangement. A direct-current dynamo of 440-volt pressure is used. The transmitting aërial is inductively coupled to the closed oscillation circuit. Many different forms of arc have been experimented with by this inventor, some with a magnetic blow-out. Simplicity of apparatus has been aimed at. The receiving arrangement consists of an electrolytic detector, battery, and telephone receiver connected with the aërial and its associated capacity and inductance. By using fairly low antennae, the Ruhmer system has operated very successfully over comparatively short distances.

Poulsen System. Special interest attaches to the Poulsen system by reason of the fact that the development of the arc method of producing sustained high-frequency oscillations was largely due to the initiative of this investigator. Mention was made of the Poulsen modification of the singing arc in its application to radiotelegraphy. Fig. 17 represents diagrammatically its application to a system of radiotelephony. A direct current from a suitable source is applied to the terminals of the arc through the secondary of a small trans-

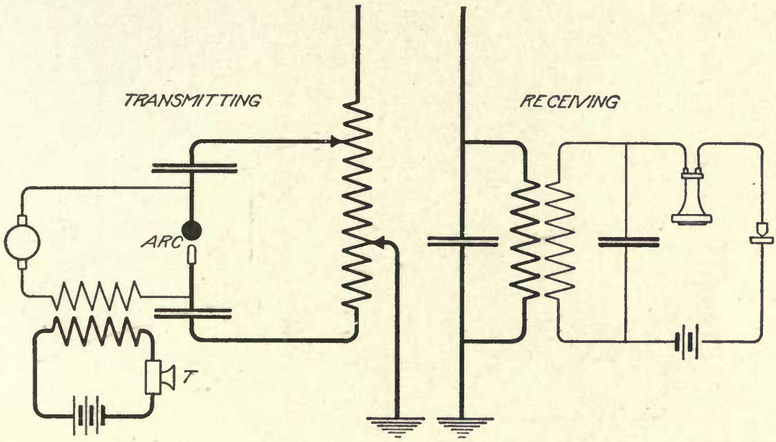


Fig. 17. Circuits of Poulsen System

former, in the primary of which is placed a local battery and telephone transmitter. The aërial is directly coupled, and two oil-condensers are so located as to prevent the direct current from reaching the aërial or ground. The magnetic blow-out devices are not shown in the cut. At the receiving station the aërial is inductively coupled with a closed oscillatory circuit which is connected with a local-battery circuit containing the detector and a telephone receiver.

Poulsen has constructed many forms of the copper-carbon arc burning in a magnetic field in an atmosphere of gas. In order to meet the difficulties caused by the irregularity of action due to the unequal burning of the carbon, he employs in connection with one form of his arc a cylindrical carbon electrode of large diameter which is slowly rotated, thus presenting constantly a new surface for the arc. In another modification, the same result is accomplished by means of a rotary magnetic field which acts directly on the arc, causing the latter to constantly change its position on the surface of the electrodes. He has also employed various gases through which the arc is maintained. In the commercial equipments more recently put out, the gas is supplied by alcohol allowed to drip slowly into the arc chamber, at a rate of about one drop every half second.

The transmitter employed by Poulsen is essentially the common carbon-granule device; he has, however, effected the variation of his oscillations by means of a multiple transmitter consisting of seven or eight such instruments connected in multiple and arranged to be acted upon by one mouthpiece.

Successful telephonic communication has been accomplished over distances varying from a few miles up to three hundred. Poulsen long-distance stations are located at Lyngby, Denmark; at Berlin, Germany; and at Cullercoats near Newcastle, England; and smaller stations are located in Denmark and elsewhere. The aërial used at Lyngby for long-distance transmission is about 225 feet high, and is of the umbrella type composed of 24 strands of phosphor-bronze wire. A 20-horse-power gasoline engine operates a 10-kilowatt, 500-volt, direct-current dynamo for the arc. A phonograph record has been transmitted from this station to Berlin and distinctly heard there—a distance of 325 miles.

The Marjorana System. In Italy radiotelephonic experiments have been carried on by Prof. Quirino Marjorana, resulting in the successful transmission of the voice from Rome to Messina, a distance of about 312 miles. As a means of creating the required oscillations, the Marjorana system employs an arc essentially identical with that used by Poulsen. The transmitting arrangement, however, is characterized by a peculiar manner of accomplishing the variations of intensity of the radiated waves. The complete circuit, including diagrammatic representation of the Marjórana liquid microphone, or transmitter, is shown in Fig. 18. The aërial is inductively coupled with the source of oscillations. The arc is fed through the blow-out magnets, which thus serve as choke coils to prevent the high-frequency current from flowing through the direct-current dynamo, which acts as supply. The receiving portion of the system possesses no points of novelty, as it is of the simple inductively coupled type and employs any of the well-known detectors suitable for this class of work.

It is the transmitter which, as suggested above, forms the distinguishing feature of this system. Its action is based upon the fact observed by Marjorana that a steady stream of water falling from an elevated containing vessel through a small orifice may have its uniformity modified by extremely minute mechanical jars imparted

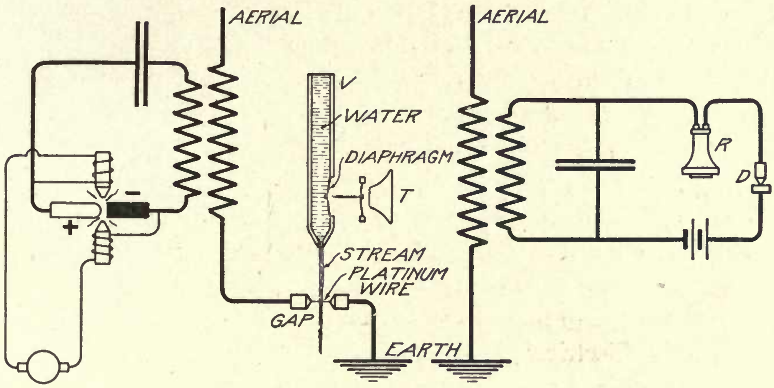


Fig. 18. Circuits of Marjorana System

to the containing vessel. The liquid transmitter is designed to take advantage of this property, and is shown partially in section in the illustration. A stationary rigid containing vessel *V* terminates at its lower end in a small hole through which the water, constantly supplied to said vessel, is allowed to flow continually in the form of a minute stream. Interposed in the path of this stream is a small gap in the aërial formed by two platinum points separated a short distance. The stream completes the connection across this gap. Means, in the form of a thin diaphragm introduced as a portion of the wall of the containing vessel, are provided to affect the diameter and contour of the stream in accordance with the vibrations of the voice. The center of this diaphragm is connected by a light rod to the center of another diaphragm which is acted upon by the voice through suitable mouthpiece. The action is as follows: The vibrations of the double diaphragm are communicated to the volume of the liquid in the form of variations of pressure manifested at the orifice and resulting in similar variations in the volume of water constituting the stream. Such modifications of the stream produce, at its juncture with the platinum electrodes of the aërial, corresponding variations in the resistance of the gap. It is of course obvious that this action produces corresponding variations in the intensity of the radiations. Numerous fluids and electrolytes have been employed by Marjorana in place of water. A form of ionized gas detector has been used in connection with this system with excellent results.

Fessenden System. In reviewing the development of radiotelephony it has been necessary to refer so often to the work of Fessenden relative to the many innovations introduced into the art by him that little remains to be said in this place in regard to the complete system which bears his name. The bibliography of radiotelephony includes many papers and articles by Fessenden of the greatest interest to the student of wireless communication. A remarkably clear and concise paper on the subject of wireless telephony, replete with much valuable data on transmission, etc., was presented by Prof. Fessenden at the 25th annual convention of the American Institute of Electrical Engineers at Atlantic City in June, 1908. Many illustrations and descriptions of the apparatus employed by him were given.

Among the many interesting facts determined by Fessenden in his very exhaustive tests dealing with the atmospheric absorption of electric waves, may be mentioned the fact that waves of a comparatively low frequency suffer less absorption than those of a much higher frequency, both being of equal power. Messages were successfully transmitted in daylight with a wave-frequency of 80,000 per second from Brant Rock, Massachusetts, to a radiotelegraphic station in the West Indies—a distance of 1,700 miles—with comparatively little absorption; while at the higher frequency of 200,000 per second communication was impossible.

The power required for radiotelephony, Fessenden states to be about five to fifteen times that required for radiotelegraphy. Fessenden has employed at various times all the well-known methods of generating a sustained train of waves but has met with greater success, particularly in radiotelephony, by the use of some form of the high-frequency alternator method, shown in Figs. 6, 7, and 12, used in connection with the heterodyne receiver illustrated in Fig. 13.

The Fessenden system has transmitted speech from Brant Rock to New York City with an expenditure of about 200 watts. Longer distances have also been covered with higher power apparatus. Fessenden's patents are controlled by the National Electric Signaling Company.

DeForest System. This system is exploited by the Radiotelephone Company and is due to Dr. Lee DeForest. It is an oscil-

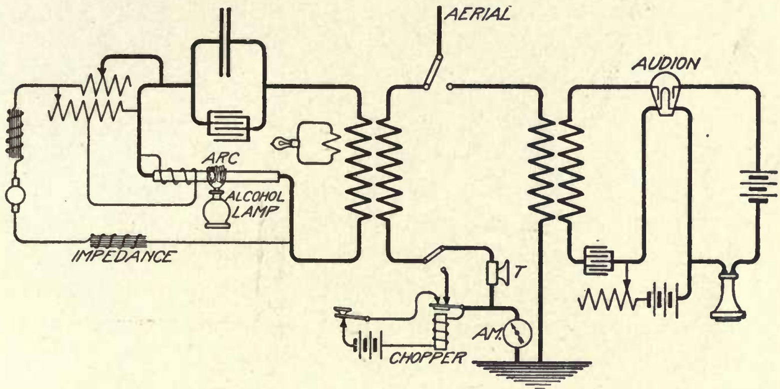


Fig. 19. Operating Circuits of the DeForest System

lating arc system presenting nothing of special novelty. Fig. 19 shows the essential features of the operating circuits, though in practice a more convenient means is provided for facilitating the change from the transmitter to receiver. The arc is of the Poulsen type, taking place between a copper positive electrode, water cooled, and a carbon negative. An electromagnetic means is provided for automatically adjusting the length of the arc by a movement of the carbon through the agency of a solenoid, which is represented in the drawing by the turns of wire around the left-hand electrode. A variable resistance is employed to effect the proper regulation of this feature. The arc is made to burn in the flame of a small alcohol lamp. The aërial is inductively coupled to the closed oscillation circuit, the latter containing two condensers connected in multiple, one of which is adjustable for tuning purposes. A small incandescent lamp, connected to a closed circuit, is placed in inductive relation with the primary of the oscillation transformer in order to give a visual indication of the proper working of the oscillation arc. The transformer used for inductive coupling with the aërial is of compact flat spiral design, the primary and secondary being placed side by side in a loose inductive couple. For telegraphic and "calling" purposes, a device for rapidly interrupting the steady flow of waves, called a "chopper," is thrown in by the movement of a switch; whereupon it becomes possible, by the operation of the Morse key, to cut up the wave-train into any desired combination of dots and

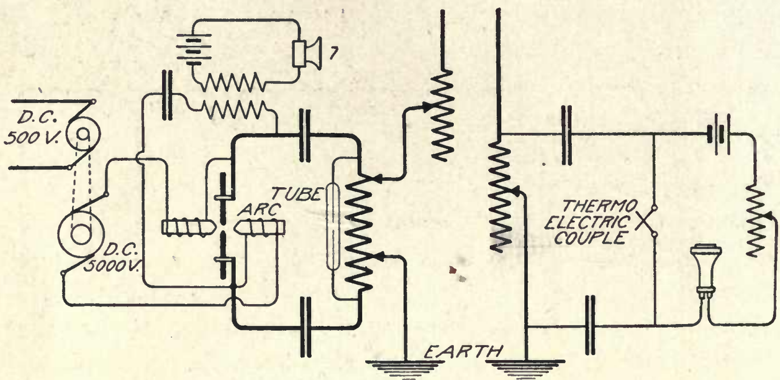


Fig. 20. Circuits of the Collins System

dashes. The telephone transmitter, which is introduced between the aërial and the ground, is out of circuit during such a performance. A hot-wire ammeter is placed in the aërial circuit to indicate when the latter is in tune. For the detector, a form of the DeForest audion receptor is used, connected in the circuit as shown.

The DeForest system has met with considerable success, and has been installed on several United States battleships. Tests have been made with the DeForest equipment by the British Admiralty, and the greatest distance over which it was possible to transmit satisfactorily was about 57 miles, a distance which has since been extended with improved apparatus. The sound from phonographic records transmitted by this system when temporarily installed at the Eiffel Tower in Paris, was said to be audible 400 miles away. This station permitted of the use of an exceedingly tall aërial, the tower being nearly 1,000 feet high.

Collins System. This system has been developed by A. F. Collins, who for several years has carried on experiments in the field of radiotelephony. The circuits employed are shown in Fig. 20, the arrangement including some unusual features though nothing in the nature of a radical departure. The oscillations are created by an arc of a higher potential than is generally used, 5,000 volts being supplied through the agency of a direct-current dynamo directly coupled to a 500-volt motor. The electrodes of the arc are both in the form of carbon disks, which are made to revolve by means of a small motor, as shown in Fig. 21. A magnetic blowout is also provided, the coils of which serve the purpose of choke-coils, thus preventing the oscillatory current from entering the generator. The aërial is of the direct-coupled type in both the transmitting and receiving stations. A visual indication of the correct working of the arc takes place in the form of a glow within an exhausted glass tube. This tube is supplied with platinum terminal wires sealed into the ends, and projecting inwardly to within a short distance from each other. This device is shunted across the inductance in the closed oscillatory circuit. The transmitter is located in a local-battery circuit and acts inductively on a shunt connected across the terminals of the arc. This shunt includes the secondary of the induction coil and a condenser. Collins has recently employed several transmitters connected in multiple and operable through a common mouthpiece. The detector employed in this system is the invention of Collins, and is in effect a sensitive thermo-electric couple composed of two dissimilar metals, the juncture of which is heated by the received oscillations. The variation of this thermal effect produces a corresponding variation in the effective resistance of the detector, and consequent vibrations of the receiver diaphragm.

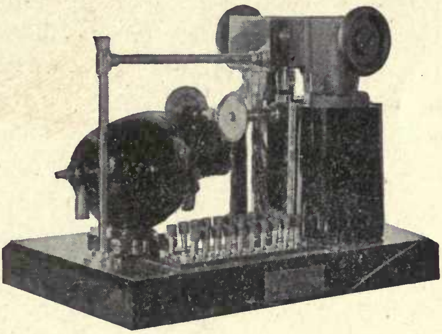


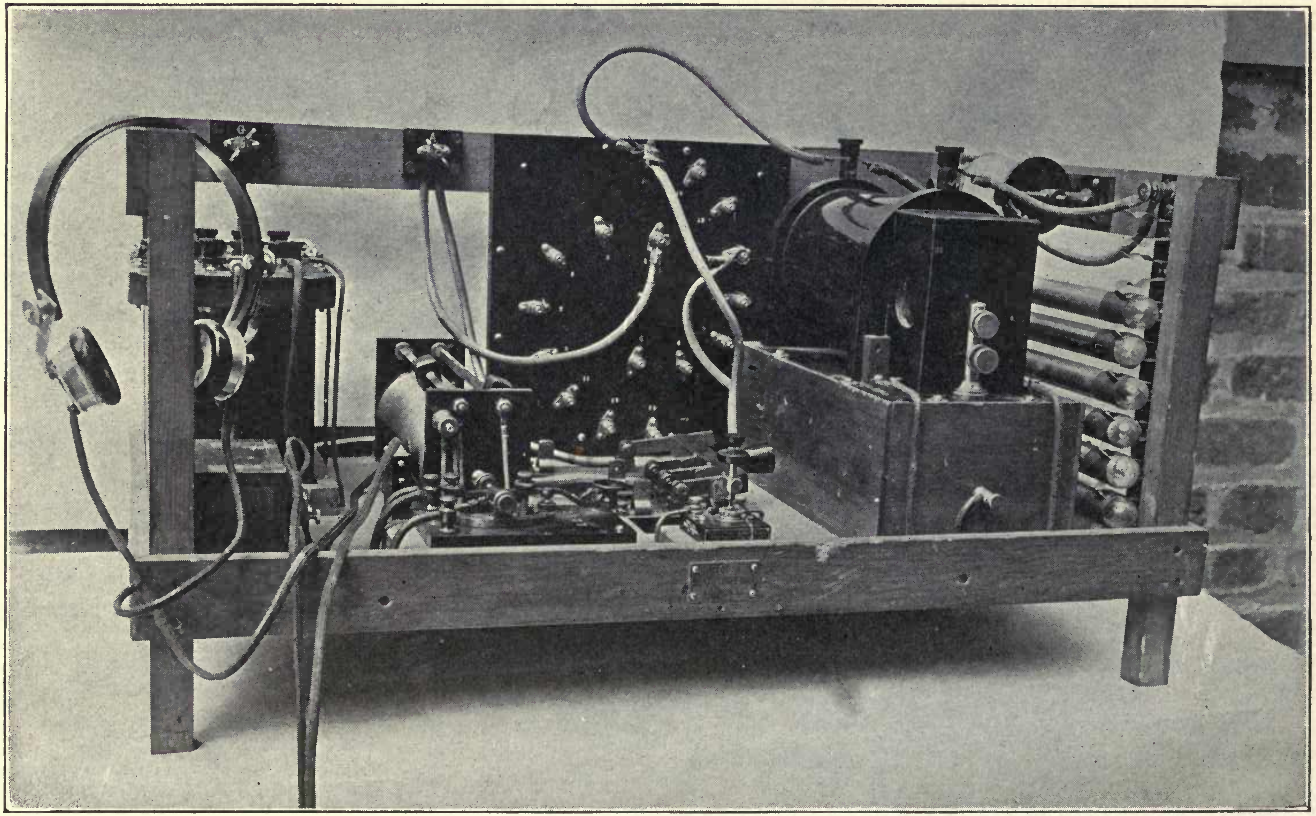
Fig. 21. Collins Revolving Electrodes

The Collins system is exploited by the Collins Wireless Telephone Company of Newark, New Jersey.

Conclusion. In conclusion attention is called to an important characteristic of radiotelephonic communication which has been observed in practice, namely, the exceptional clearness of articulation, due to an absence of wave-form distortion which is always present in wire telephony by reason of the deleterious effect of the electrostatic capacity of metallic lines and cables. This fact alone bespeaks wonderful promise for this form of telephony, particularly in view of the very limited distance over which it is at present possible to telephone when the medium is a submarine cable.

Experience has thus far shown that great advantage is to be gained by the very accurate tuning of the various circuits in connection with radiotelephony as well as with radiotelegraphy. The employment of sustained oscillations greatly facilitates the accomplishment of more perfect resonance; which, in turn, tends to eliminate interference and aids selective communication. Experience has also shown that in systems using an inductively coupled aërial, a decided gain in the clearness of articulation is noticeable when such coupling is "loose." In practice, therefore, the primary and secondary helices are often separated several inches.

In the foregoing discussion of radiotelephony it has been impossible to do more than very briefly present the subject. Many interesting questions of a theoretical nature and a description of several other systems, it has been found necessary to omit. If, however, the present short survey awakens a greater interest in space-communication, the reader may avail himself of the extensive literature dealing with the subject, and delve as deeply into the theory and problems involved as he desires.



THE NEW AËRIAL WIRELESS SET DEVISED BY GOVERNMENT ELECTRICIANS
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WIRELESS TELEGRAPHY IN AERONAUTICS

WIRELESS ON DIRIGIBLES

Early Experiments on Balloons. It will be apparent that one of the most valuable features of the use of the dirigible and the aeroplane in warfare is the possibility of communicating with headquarters by wireless telegraphy, which means the instant reception of information gained by scouting parties. Not long after the invention of sending messages through the air became a reality, Professor Slaby demonstrated that wireless signals emitted by a land station can be received by a balloon, floating freely in the air. The experiments were carried out in conjunction with the maneuvers of the Prussian balloon corps, and since then experiments have been made successfully in other countries. The balloon Condor, which made an ascension near Brussels, in the latter part of 1909, maintained uninterrupted communication with the station on the Brussels Palais de Justice, and also caught signals sent from the Eiffel Tower at Paris, 180 miles distant. Prior to this, Professor Hergesell had already demonstrated the great value of the application of wireless telegraphy to balloons by controlling the valves of unmanned sounding balloons (small balloons sent aloft for the purpose of carrying meteorological instruments), at heights extending to ten miles, by wireless impulses. The receivers of the balloons were tuned to different wave lengths, so that the valve of any one balloon could be opened and that particular balloon brought down at will.

In a series of experiments made with the German military balloon Gross II, in the autumn of 1908, messages were sucessfully sent from, as well as to, the airship, the first balloon wireless stations being constructed according to the Telefunken system. It was proved by preliminary experiments in the balloon shed that the danger of igniting the contents of the gas bag by sparks emitted from the wireless apparatus could be averted by taking suitable precautions.

This danger is least with airships of the flexible and semi-rigid types, in which the gas bag possesses very few metallic parts that could draw sparks from the highly charged aerial which is used for sending and receiving the flashes from the air. The suspension of the car of the Gross by hempen ropes insured the complete insulation of the electrical apparatus from the gas bag, and all parts at which sparks were formed were enclosed in gas-tight envelopes. For military reasons, the details of these experiments were not made public, but the results are said to have been very satisfactory.

These experiments have proved that electro-magnetic waves are propagated to great heights in the atmosphere and that the part played by the earth in wireless telegraphy is far less important than has been assumed. Thus, one of the principal theoretical objections to the application of wireless to airships has been shown to be fallacious. In the German army maneuvers of 1909, the Gross II demonstrated, for the first time, the practical utility of wireless telegraphy on a scouting balloon. The Zeppelin airship which took part in the maneuvers did not possess this advantage. Subsequently the Zeppelin III was equipped with wireless apparatus and it was shown that even with a rigid, metallic-framed airship of this type, wireless signals could be transmitted with safety to a distance of 300 miles or more. All of the later Zeppelin airships which have since been wrecked, and particularly the passenger-carrying types, were equipped with wireless.

Dangers from Electric Discharge. While of inestimable advantage, the presence of the wireless apparatus on a metallic airship exposes it to new dangers, some of which are also present in the case of the aeroplane. The chief source of risk is the large volume of inflammable gas necessary for flotation in the case of the huge dirigibles. In a thunder storm, a balloon is subject to sudden variations of electric charge which may produce sparks capable of igniting its contents. Wireless signals are accompanied by equally great and rapid changes of potential which may produce the same result.

It seems probable that the destruction of the Zeppelin airship at Echterdingen was due to atmospheric electric discharges during a thunder storm, while the catastrophe which befell the French military dirigible La Republique in September, 1909, also appears to have been due indirectly to an electric spark. A hole was torn in the gas bag by the breaking of a propeller blade, which in itself would not have been sufficient to have caused the sudden drop of 300 feet. It is a well-known fact that gas or steam, escaping rapidly from an orifice, will acquire an electric charge which may produce powerful sparks, and it is thought that this took place immediately following the rupture of the gas bag of the Republique, setting its contents on fire.

As the gas can not be ignited by discharges from the envelope itself, the netting, ropes, and similar poor conductors (unless they become saturated with water), but can be easily set fire to by sparks from the metal parts of the valve and other masses of metal, it is obvious that all metal and other good conductors will have to be eliminated from the envelope. There seems to be no objection to the presence of metal in the car, while a well-conducting drag rope is a safeguard against explosion in landing. If all conductors are removed from the vicinity of the gas bag, there would appear to be no danger in the application of wireless telegraphy to airships of the flexible type. If the same precautions be taken, dirigibles of this class are no more liable to ignition by atmospheric electrical discharges than the free balloon.

In rigid airships with metallic frames, the conditions are totally different. It will be apparent in the Zeppelin type, with its aluminum frame and its numerous gas bags filled with hydrogen, every condition of easy ignition is present. Between the great cylindrical conducting frame, which is more than 400 feet long and 40 feet in diameter, and the surrounding air, there may exist a difference of potential of 65,000 volts when the airship is horizontal, and of 50,000 volts, when steeply inclined. A spark capable of causing ignition may be caused by a difference of potential of only 3,000 volts. As it does not appear to be practicable to substitute wood for the aluminum framing, Zehnder recommends protection of airship by lightning rods projecting beyond the reach of escaping gas, He also suggests making the gas container of sheet metal, the stiffness of which might make it possible to employ a lighter skeleton, thus keeping the weight within the same limit as at present. No electrical discharge could take place within this metallic envelope and the induced surface charge would escape harmlessly into the atmosphere from projecting seams and points. As an additional precaution, the aluminum cars could be connected with the aluminum balloon at several points by a number of wires, so that the aeronauts would be enclosed in a sort of Faraday's cage, protecting them from external electrical influences.

Preventive Methods. The experiments of Professor Wiener have not only served to demonstrate the value of a wire cage as protection against electrical discharges, but likewise have illustrated what happened to a balloon when struck by a spark. For this purpose, a model balloon was suspended above a large induction coil with the gaps of the secondary so arranged that the largest diameter of the balloon was between one pair, while a second pair was located to discharge immediately below the valve opening of the balloon. When a spark was passed completely through a collodion balloon, filled with either hydrogen or illuminating gas, the gas ignited without explosion so that the balloon was quietly consumed. It is only when the balloon contains air mixed with gas that explosion takes place. A balloon can even be traversed by sparks without being ignited. Metzeler has recently introduced a balloon material composed largely of aluminum for the purpose of protecting the gas from the sun's rays, but experiments prove that this material is no better conductor than the ordinary balloon fabric. Sparks can be passed through a balloon of Metzeler's material without causing ignition and even collodion balloons can transmit a few sparks without burning. If the flow of sparks be so rapid and dense as to resemble a flaming arc, it may directly ignite the fabric. Even if it were possible to make a balloon of conducting material, it would still be desirable to surround it with a wire cage, as lightning naturally follows the shortest path. With this provision, the conductivity of the balloon is of no importance. Owing to its greater strength the wire netting need not be heavier than the hemp netting ordinarily employed on dirigibles of the flexible and semi-flexible types. All the experiments just referred to were made with unprotected balloons, but a model surrounded by a wire cage allowed ordinary sparks to pass indefinitely, while it also withstood a flaming arc for a short time, without igniting. Fifteen seconds direct contact with the flame was necessary to produce ignition. The ropes supporting the car must also be of wire and must completely surround the car. It might be supposed that making the outside of the balloon a good conductor would rather invite danger from lightning, but this is not the case. Although the ordinary balloon envelope is a fairly good insulator against low voltages, it is unable to resist the high tension of atmospheric electricity. An electroscope charged to 2,000 volts is discharged in less than a second, when it is touched with a roll of balloon fabric about six inches long. Hence, the balloon increases the electrical tension immediately above and below it, as much as it would do if it were a perfect conductor, but when the discharge occurs, its destructive action will be greater in proportion to the electrical resistance opposed to it. It might also be objected that the Faraday's cage would prove a source of danger to the occupants. The discharge, however, passes chiefly through the wires, and only partial or inductive discharges can strike those in the balloon. It is evident that the Faraday's cage is quite as readily applicable to the aeroplane as it is to the dirigible, through its use might complicate the employment of the aerial for wireless telegraphy, as referred to later.

On the other hand, it is quite possible that the surrounding network of wire might be employed for both purposes by suitably protecting the instruments. But even when a balloon is thus protected from lightning, it is exposed to another danger, atmospheric electricity. A balloon has been ignited and consumed by small sparks produced by touching the escape valve after landing. This valve and the filling tube, normally open during flight, are the two places in which the gas can come into contact with the air and therefore need special protection. The simple and long-known device employed in the Davy safety miner's lamp can well be employed for this purpose. These safety lamps are designed to protect miners from explosions of fire damp, the flame being surrounded by a fine wire netting which conducts heat so well that the temperature required to ignite the gas can not be produced on the outside. Any gas which enters the lamp burns quietly without producing an explosion. Both the escape valve and filling tube of the balloon could be surrounded with a fine netting of copper wire, which would also afford protection from lightning in certain cases.

An electric discharge may be precipitated by pulling the valve cord in a strong electric field, as, according to Paschen's experiments, the gap that a certain tension will bridge is greater in hydrogen than in air. This is shown by connecting a Bunsen burner with one pipe of an induction coil and gradually raising the other above it until the opening is too great for the sparks to bridge. Upon turning on the gas, the flow of sparks will recommence. If the burner be surrounded with a wire netting, the gas will burn only on the outside. The experiments with the model balloons and a large induction coil showed that when the sparks passed beneath the open filling tube of the balloon, ignition sometimes followed, but where protected by a wire netting, a flaming arc playing upon the netting for a minute did not light the gas.

Wireless on the Zeppelins. In regard to the employment of wireless telegraphy on the Zeppelin type of the present form—an arrangement of the aerial which would minimize the danger of ignition and would also furnish the best electrical conditions for the transmission of signals, is suggested; as the hull of the Zeppelin is traversed by a vertical shaft or well, it is possible to support the aerial by a simple Eddy kite, which would be kept aloft by the motion of the airship. The wireless apparatus, including the dynamo, would be housed in the middle of the runway which connects the two cars. The kite would be connected with the apparatus by a wire from 600 to 1,200 feet in length, *i. e.*, one-fourth to one-fifth the length of the electric waves employed. A second wire of the same length and carrying a weight at its end would hang downward from the apparatus and would be kept as nearly vertical as possible by insulated stay or guy lines attached to the cars. The lower wire might, however, be replaced by a fan-shaped antenna about 200 feet long, attached to the frame of the airship and projecting about 30 feet below the hull. With this arrangement communication would be possible even when the ship was flying low. Fouling of the propellers would have to be guarded against by enclosing them in wire baskets or housings.

The **T**-shaped antenna which is carried by ships using the Telefunken system, could also be applied without difficulty to the Zeppelin airship, as the metal frame is abundantly able to carry a light, hollow mast about 30 feet high, which could be raised and lowered by ropes. The stability of the airship, however, would be affected more by this complicated device than by the kite. Experiments have shown conclusively the great promise of the use of wireless telegraphy on airships, but an indispensable prerequisite to its adoption would appear to be the electro-technical development of means of protection from all danger of injury through the working of the apparatus itself, or from atmospheric electricity.

WIRELESS ON AEROPLANES

Owing to its far greater speed and radius of action as well as its more general availability, the employment of wireless telegraphy on the aeroplane holds far more promise for military use. With experience in taking observations from a height it will become possible to plot maps, note the character of emplacements, and the position of troops from an altitude that would make danger from shell fire from below out of the question. To be of any value, the dirigible must be so large as to make this impossible.

First Message. To James McCurdy, one of the Curtiss school aviators, belongs the distinction of having been the first to communicate by wireless from an aeroplane to a land station. This was on August 27, 1910, when he sent the following message from a Curtiss biplane:

Over Barren Island, N. Y., 6:45 P. M., Aug. 27, '10.

To H. M. Horton:

Another chapter in aerial achievement is recorded in the sending of this wireless message from an aeroplane in flight. McCurdy.

Horton was the wireless operator on the roof of the Sheepshead Bay race-track grand stand, two or three miles distant from Barren Island, though the distance was probably less in an airline. The apparatus was an ingenious makeshift merely intended for the purpose of sending and was not capable of receiving a message. It was extremely compact, the complete outfit, with the exception of the battery, being attached to the steering wheel of the aeroplane. The battery was carried in the aviator's vest pocket, while the aerial consisted of 50 feet of ordinary wire held straight by a small lead weight, the whole trailing after the machine in flight. Such an outfit naturally had but a very limited range, probably not more than five miles, owing to the small amount of energy available, and would be subject to destructive interference from the waves sent out by more powerful stations in its vicinity. It was intended only to demonstrate the possibility of communicating with an aeroplane in flight.

Owing to the high speed at which an aeronautic motor runs, however, it would be practical to carry a very compact alternating generator which would weigh very little and still give the aeroplane sending station a comparatively wide radius of action—doubtless up to 100 miles or more, due to the greater facility with which the electromagnetic waves can be transmitted from a height. The remainder of the apparatus could likewise be made in very compact and durable form, so that there would appear to be no "wireless problem" where the aeroplane is concerned—it is merely a matter of designing instruments for the purpose.

Horton's Experiments. The question of equipping the aeroplane with a suitable aerial that would be effective without being an encumbrance, as well as the fact that a very substantial percentage of the energy emitted by the sending apparatus was absorbed by the numerous guy wires which also acted as a shield to the antennae, appeared to present a difficult obstacle at first. Both, however, have been overcome by a very simple expedient, that of employing the guy wires themselves as the antennae. After experimenting for a long while with numerous different methods of stringing separate antennae, H. M. Horton hit upon the idea of using the wires for this purpose, while the motor is utilized as a ground. Experiments which were made with a machine thus equipped and located in the building of the United States Aeronautical Reserve in New York City, proved most successful. Messages were received from various stations throughout the city and even from ships at sea, despite the fact that the aeroplane was located on the first floor of the building and was not connected with any form of antennae protruding above the roof. A very light equipment was used, the total weight not exceeding 65 pounds, although a 6-inch spark coil was employed. Energy is derived from a 12-volt storage battery with a 50-ampere-hour capacity, the six cells weighing but 40 pounds. The guy wires are connected in series and give a total length of 800 feet on the machine in question. However, the employment of a storage battery in this connection can be considered only as a tempory expedient, in view of the obvious limitations of such a source of energy. For extended practical use, a generator would be necessary. As the required power is right at hand, this could take the form of a small high-frequency alternator, and as this could be wound for a high voltage, the weight of the transformer necessary could be correspondingly reduced.

Recent Records. *Lorraine.* Numerous other experimenters have been at work with wireless during the past year or so, Robert Lorraine, in England, having succeeded in maintaining perfect communication from his aeroplane with a land station more than a mile distant.

Beck. The most practical results, however, were those of the trials carried out during the course of the aviation meet at San

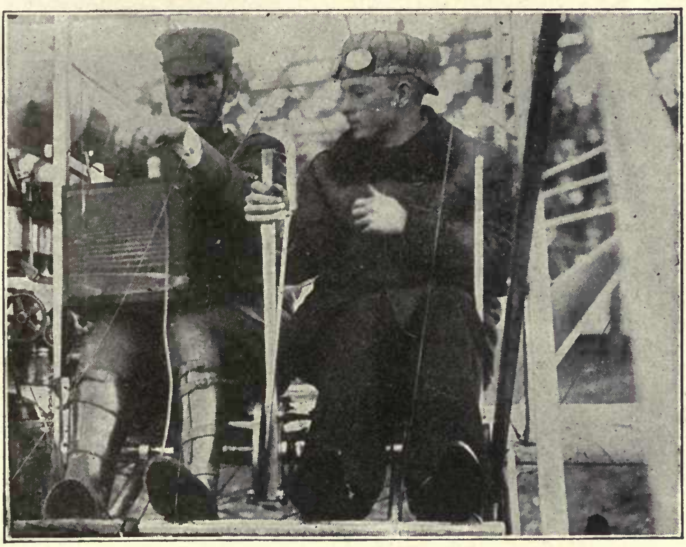

Fig. 1. Parmalee and Lieutenant Beck in a Wright Biplane, Operating a Wireless Outfit

Francisco in January, 1911. Lieutenant Paul W. Beck of the United States Signal Corps went aloft in a Wright biplane piloted by Parmalee, Fig. 1, and transmitted wireless messages for a considerable distance while at a height of 1,000 feet. These messages were received at the Mare Island Navy Yard, 40 miles away, as well as at the Yerba Buena Island training school in San Francisco Bay. In Lieutenant Beck's experiments a 100-foot length of copper wire was trailed along behind the aeroplane. In France, wireless messages have been transmitted 15 miles from an aeroplane successfully, while in England, during a trip of the military dirigible

Beta, communication was established with headquarters, 30 miles distant.

McCurdy. During the Bridgeport, Connecticut, Aviation Meet in May, 1911, McCurdy set a new long-distance mark in wireless communication from an aeroplane by sending messages to the operator in the dome of the World Building in New York City, 55 miles distant, while a number of other stations within a shorter radius also picked up his messages. The apparatus was constructed for the *New York World* in three days by Oscar Roesen, an electrical engineering student at Stevens, and was probably the first set capable of both sending and receiving that has been mounted on an aeroplane. The transmitter consisted of a 4-inch induction coil of the

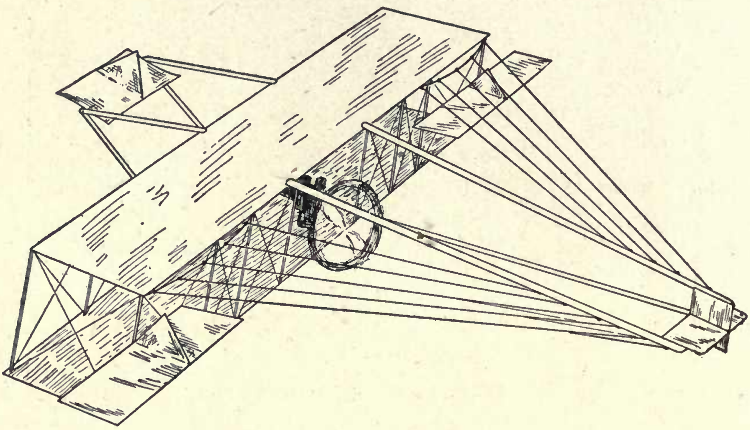

Fig. 2. Diagram Showing Method of Making an Aerial on a Biplane

ordinary vibrating type, supplied with current by 15 dry cells connected in series, thus giving a voltage of 22.5, while the amperage was high. The helix was a wood frame 5 inches in diameter and wound with 12 turns of No. 6 B & S gauge aluminum wire, while the condenser consisted of copper plates with a special insulating material as the dielectric. An ordinary telegraph key was employed. The receiver comprised a mineral detector, two straight tuning coils, and a pair of 2,000-ohm head phones. The aerial consisted of a series of wire strung forward from the tail on either side to points directly above the ailerons at the ends of the upper plane of the Curtiss machine, Fig. 2. For a ground, or rather for a balancing aerial, the motor, supplemented by wires carried out in either direction to the ends of the main plane, was employed. The apparatus proper was mounted in a small box carried below the aviator on the skids of the machine, while the sending key was placed on the steering wheel. The arrangement is plainly illustrated by the accompanying sketch, Fig 3. *A* is the box, *B* the key, dotted lines *C* the ground or balancing aerial, and full lines *CC* the aerial proper. The weight of the outfit was between 40 and 50 pounds. Lieutenant Fickel, U. S. A., detailed by the War Department to attend the meet, was very much impressed with the set and sent a complete description of it to the Signal Corps at Washington. Experiments were first made on a Saturday and while McCurdy's signals were

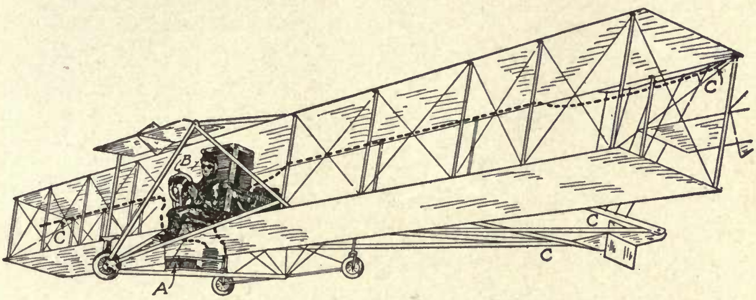

Fig. 3. Diagram Showing Location of Circuits and Equipment of a Wireless Outfit

plainly heard at the temporary receiving station on the field, the interference of numerous adjacent stations made it impossible for the operator in New York to pick them up. On the following day, there was an absence of interference, and the messages were plainly heard in New York on three different trials, thus establishing a new distant record for aeroplane work, and this is of even greater importance in having reached the heart of the metropolis, as New York City is generally conceded to have many adverse elements for successful wireless reception from outside points, chiefly due to the great number of high, steel-frame buildings. Tests which were made of the receiving abilities of the set showed that it was abundantly capable of picking up messages from a distance of 200 miles, but, unfortunately, no actual trials of this nature were carried out in the air.

General Problems. It will be apparent from the foregoing that all of the experiments made thus far have been in transmitting messages from an aeroplane in flight, and while this is a very valuable accomplishment, receiving is quite as necessary, to take complete advantage of the value of the wireless as a means of communication, and for reasons that are obvious this does present more of a problem than the mere sending of messages.

Eliminating Noise. The chief difficulty is that of noise, as with the unmuffled motors now generally in use, it is practically impossible for two men sitting side by side in an aeroplane to carry on a conversation. This is further complicated by the rush of the wind and the high pitched note occasioned by the vibration of the numerous guy wires and struts, but with close-fitting, double-head receivers, there should be no difficulty in shutting out practically everything but the noise of the motor. The matter of expediency that has been responsible for the adoption of so many of the makeshift features of design that characterize the present-day aeroplane, and probably will continue to do, at least for a few years to come, has likewise been responsible for the elimination of the muffler on the motor. But even now, design and construction have advanced to a point where there is really no necessity for longer doing without this essential, as both the muffler and its connecting pipe can readily be made of aluminum, though, for that matter, the weight of the standard type as employed on the automobile would not form any very serious drawback. Considerably more difficulty would be encountered in muffling motors of the rotary type, but they need it least, as the explosions of a seven- or fourteen-cylinder Gnome motor running at full speed overlap to a degree that converts the exhaust into a loud buzz, rather than the disagreeable and ear-cracking rapid-fire bang of the four- or six-cylinder vertical motor.

Use of Visible Signals. Should the usual audible method of receiving not prove practical, two alternatives are open, both involving the use of a visible signal. In one, a coherer could be connected with a tuning condenser shunted across it, the former being automatically decohered every two seconds by a striker actuated by a magnet excited by a clockwork contact maker. A relay and battery are connected in series with the coherer, and the local circuit of the relay is connected with another battery and small incandescent lamp. Each time a signal is received the lamp would light—one second for a dot and two seconds for a dash. These long signals are obviously necessary, but in spite of that a message could be received with reasonable rapidity. The second alternative is that of employing an inker, this method also involving the use of a coherer. The inking apparatus, however, is not only comparatively heavy, but in order to work satisfactorily, requires fairly close adjustment, so that it would not be suitable for use where there is much vibration. The question of vibration is probably the most serious element of the problem. The coherer is not a particularly sensitive receiver of the weak impulses which have to be caught, and has long since been practically abandoned in wireless practice. But even if it were sufficiently sensitive for such use, it would probably be impossible to make the coherer work long enough to start the local side of the relay working effectively, particularly if the mechanical decohesion had to be rapid. In fact, the actual number of impulses per second of a four-cylinder, two-cycle engine, or a six-cylinder, four-cycle, or any of the rotary motors, is too great to permit a coherer to act, while a coherer insensitive to the abruptness of the shock would not be sensitive enough to respond to the wireless impulses. Either the mineral or the electrolytic type of detector is far more sensitive, but as its adjustment must be delicate to work effectively, it would also be placed at a serious disadvantage by the vibration.

Forms of Aerial. The question of the most practical form of aerial to employ is another difficulty that affects both sending and receiving. The use of a long trailing wire, as well as the employment of the network of guys and braces, has already been referred to in connection with experiments carried out by McCurdy and American army officers. Trailing wires present so many sources of danger to a machine traveling at high speed, that few pilots would care to consent to their use, while connecting up the bracing of the aeroplane is equally impracticable as every piece of metal on the machine then becomes charged, and in sending, serious shocks might be received by the pilot or his passenger. Farman has employed two trailing wires, each about 400 feet long, and Baker has adapted a similar arrangement to a Bristol biplane in England, the wires, however, not being allowed to hang loose in the latter case, thus limiting their capacity. Instead of using balanced aerials, as in the

McCurdy experiments described above, he coupled them to each end of an inductance coil, thus increasing their effective length to the greatest extent possible without sacrificing their efficiency. The apparatus consisted of a 6-inch induction coil with a ⅝-inch spark gap located as far away from the gasoline tank as possible. Two light brass rods extended from the coil well into the space between the two main planes of the machine and to one side of the tank, and two ⅜-inch rods sliding on these and with their ends separated by ⅝ inch, formed the spark gap terminals. Shunted across the spark gap was a condenser of the Leyden jar type, and an inductance coil consisting of seven turns of No. 14 copper wire wound on a light ebonite drum. This inductance had sliding contacts so that the number of turns used could be varied in the usual manner, in order to tune the two circuits. The two aerial wires were connected to the two ends of the inductance in use and the aerial circuit was brought into tune with the shunt circuit. A storage battery of five cells supplied the necessary energy, about 50 to 60 watts being required. Two new arrangements which should greatly increase the efficiency of the apparatus have since been adopted. The more important of these is a long, light brass tube attached to the tail of the aeroplane but insulated from it. This acts as counter-capacity or "ground" to a long aerial wire on the other side. This aerial starts from the nose of the machine, and is carried thence to the extreme outer edge of the main plane, back to the tail, and from this to a loose connection, 60 feet of copper wire trailing behind.

Possible Developments. It is evident that these isolated experiments, while more or less numerous, are but the beginning of the serious study that will be given the matter within the next year or so. Nine-hour, non-stop flights covering more than 400 miles give some idea of what will be accomplished in the way of long-distance flying in the near future—in fact, they make the possibility of being able to cover more than 1,000 miles per day of twenty-four hours seem very close at hand, so that Atwood's proposal to fly across the Atlantic in three days appears to be only a question of carrying sufficient fuel. To be able to keep in constant communication with these long-distance flyers would be invaluable, and that is what experimenters in the wireless field aim to accomplish.

Wireless telegraphy from the dirigible has already reached a more advanced stage, as neither the use of a trailing wire nor the matter of weight present such serious disadvantages as on the aeroplane. The apparatus used on the British military dirigible Beta weighed approximately 100 pounds, and as signals have been sent 50 miles under favorable conditions, the proportions of weight to distance of transmission was, roughly speaking, 2 pounds. But an ordinary induction coil and accumulator were employed, so that this can scarcely be taken as a criterion. They were used in connection with a trailing aerial and a counter-capacity, and, as the chief requirement of the latter is superficial area to take the charge, as light a substance as possible, such as paper-thin sheet aluminum, could be employed.

The form of the wireless installation suggested by one of the chief English experimenters as best adapted to the needs of the airship, is that of a small auxiliary motor, say, a two-cylinder, 3- to 4-horse-power machine, directly coupled to an alternating generator of about 2 kilowatts capacity, together with an aerial about 350 feet long, and a counter-capacity in the form of very thin metallic sheeting, suitably disposed. Considerable attention is now being given to the production of portable apparatus. The chief limiting factor in connection with small receivers naturally has to do with the detector, the vacuum valve type of Prof. J. A. Fleming probably being the most suitable in many respects, and next to that an electrolytic detector.

Akron Outfit. The ill-fated dirigible Akron, in which Melvin Vaniman had intended making his second attempt at crossing the Atlantic, when he and his gallant crew were killed by the fall of the airship due to the explosion of the gas bag, is a forcible example of the careful attention now being given to wireless equipment and the dependence placed upon it as a safeguard. Vaniman was particularly fitted by experience to judge of the wireless requirements for a dirigible, as, it will be recalled, he was Wellman's chief engineer on the America, and he had taken advantage of that experience to embody all the improvements in the new equipment that were found lacking in the America's set. The latter had a sending range of only 80 to 90 miles, so that while the operator could catch the numerous inquiries that filled the air regarding the America's whereabouts during the 48 hours or more that it was out of sending range, he could not reply to any of them. The equipment of the Akron was a Marconi set with a sending range of 700 to 800 miles and consisted of a 3-kilowatt, 120-cycle, alternating-current generator, direct driven by a 17-horse-power, 4-cylinder gasoline engine. For receiving, the most advanced type of musical, rotary spark gap and a valve detector was to be employed. As a counter-capacity does not permit of the most efficient operation, a flexible, phosphor bronze wire trailing in the water was to constitute the ground, the equilibrator which was used for that purpose on the America having been abandoned. This trailing ground was wound on a drum and sufficient wire was provided to reach the water at any point from 100 to 1,200 feet elevation, the amount payed out depending upon the height at which the airship was flying. However, should the airship rise higher, provision had been made to operate the equipment as an unbalanced Hertz oscillator without a ground. The transmitter was of the loose-coupled type and was so arranged that considerable variation in the natural period of the open oscillating circuit would have a minimum effect upon the transmitted signals. The frame of the envelope was used as one side of the oscillator, the trailing ground acting as the other. Particular care had been taken in the design of the various parts of the apparatus to prevent any possibility of the sparking, or high-tension discharge, igniting the hydrogen gas. Jack Irwin, whose call of distress from the America brought the S.S. Trent to their rescue, was to have accompanied the Akron as operator.

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