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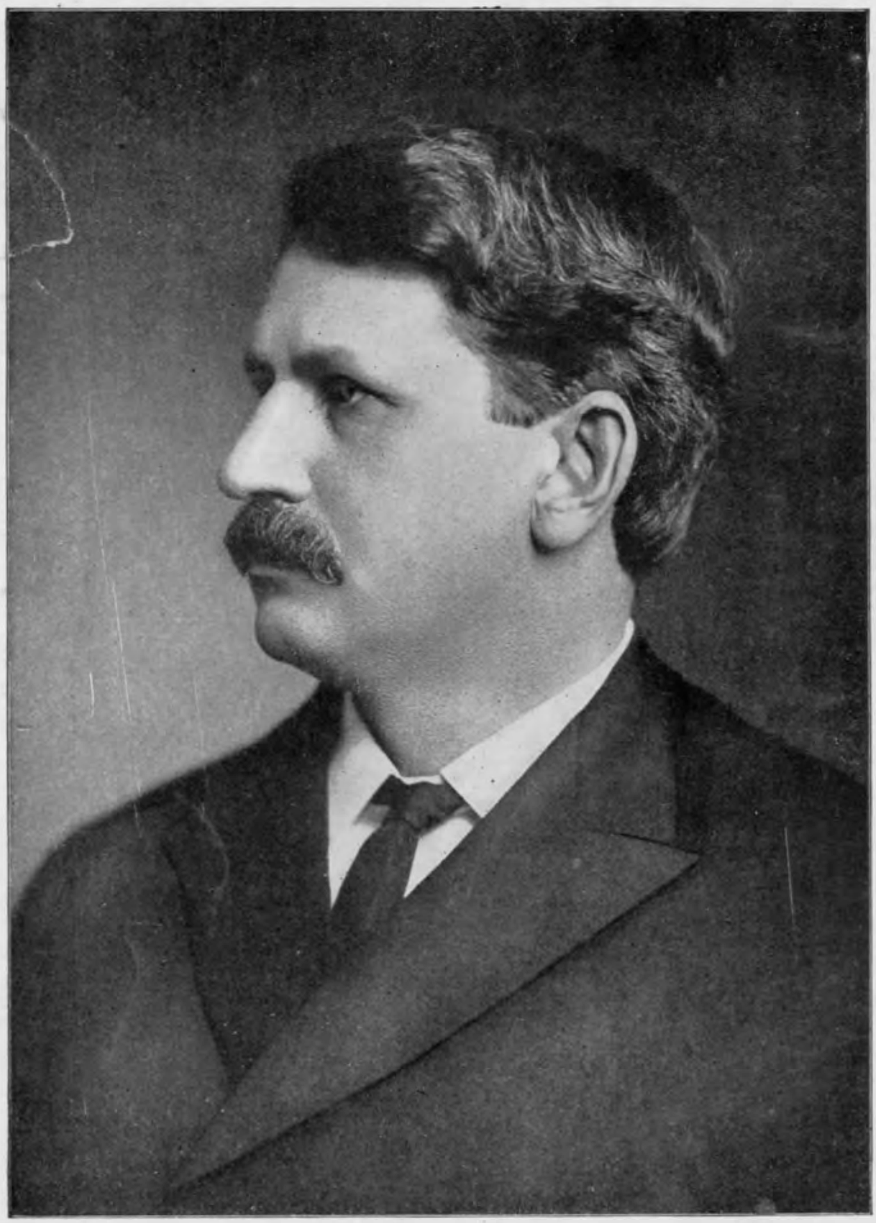


FRANK W. GUNSAULUS,

President Armour Institute of Technology.

H.M.S. RUSSELL. LONG DISTANCE WIRELESS TELEGRAPH EQUIPMENT.

Marconi System.

The American Marconi Co. is Financed by Munroe and Munroe.

WIRELESS TELEGRAPHY.*

HISTORY.

The practice of signaling through space may be traced back through the ages to the beginning of the history of mankind, for the earliest records indicate that the survival of the fittest sent powerful sounds from his lips through the air, and that for longer distances he employed fire to propagate light waves through the subtler medium of the ether.

As civilization advanced, the necessity of transmitting intelligence to a longer distance and with a broader interpretation, led to the introduction of many forms of intercommunication, made possible by the invention of writing and the use of semaphores, but these were not without their special limitations since the former consumed time in transportation and the latter could be operated only where a direct visual line between the sender and receiver was possible.

With the advent of experimental electricity and the knowledge of its properties for traversing long lengths of wire with practically the speed of light, came the burning desire to utilize it for the transmission of messages, but we need not here dwell upon the remarkable events that gave us the electric telegraph, the submarine cable and the speaking telephone, for these do not form a part of the subject herein treated; but instead we shall follow the evolution of that allied and newer branch of the art called *wireless telegraphy*.

For at least a century before an electric impulse, representing a signal, had actually been transmitted and received without intervening and connecting wires coupling the two opposite but complementary instruments, the subject was a favorite one with the physicist, and it is not unlikely that the ancient Greeks who witnessed Thale's experiment of transferring energy from electrified

*** Prepared especially for the Cyclopedia of Applied Electricity by A. Frederick Collins, Author of " Wireless Telegraphy, Its History, Theory and Practice."**

amber to neutral paper, dreamed of the bridging of greater distances by the same mysterious influence.

The first recorded instance, however, in which a definite scheme was proposed having for its object the telegraphing without wires by electricity, was that given by Silva, a Spanish physicist, who read a paper "On the Application of Electricity to Telegraphy" before the Academy of Sciences on Dec. 16, 1795, at Barcelona. In this prophetic memoir, he advocated that a given area of earth be positively electrified at Mellorca and that a similar area of earth be charged to the opposite sign at Alicante; the sea connecting these two cities would then act as a conductor when the electric difference of potential would be restored, and by a proper translating device the transfer of energy could be indicated.

Conductivity Method. The first experiment resulting in the successful transmission of electricity between two points without an artificial connection may be ascribed with considerable certainty, to Steinheil of Bavaria, who made the important discovery that the earth could be utilized in place of the usual return conductor of a wire telegraph line. After ascertaining the fact that current traversing such a circuit flowed in innumerable curved lines between the terminals of the line wire embedded in the earth, Steinheil then found that by placing a similar pair of earth plates, 3, 3′ and 4, 4′, likewise connected together and having a galvanometer 5 interposed in the circuit, parallel with the first, which included a battery and a key 2, as shown in Fig. 1, there was a sufficient dispersion or leakage of the current from the one to affect the other to the extent of deflecting the needle of the galvanometer. The dotted lines represent currents in the earth.

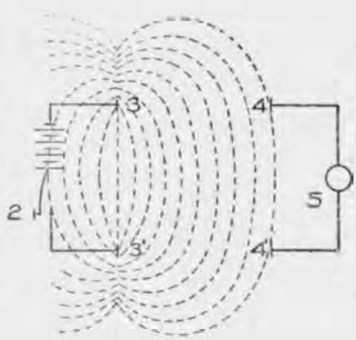


Fig. 1. Conductivity Method.

These pioneer experiments were made in 1838, the discoverer having proven it possible to obtain calculations at a distance of at least 50 feet, this forming the basis of what is now known as the *dispersion* or *conductivity* method of wireless telegraphy. This mode of transmission has been thoroughly tested by many investigators since its inception until 1892 when Preece, of England, obtained results from Lavernoch Point to Steepholm in the Bristol Channel, a distance of nearly five and a half miles.

The invention of the telephone receiver by Bell opened fresh fields in the realm of signaling through space, owing to its extraordinary sensitiveness; and by means of this remarkable instrument an effort was made to determine the inductive effects of telephone circuits. This was attempted in 1877, by Saches, of Austria, who arranged two parallel circuits, each forming a loop 120 meters in length with a distance of 20 meters separating them. A current from three cells was employed for exciting the first circuit, and this was found ample to produce distinctly audible signals in the telephone receiver.

Inductivity Method. Following these researches, Trowbridge, of Boston, carried on a large number of experiments in electromagnetic induction, the arrangement of which is illustrated in Fig. 2. In this method, two coils of wire 3 and 4, formed of many turns, are placed in parallel, or in a plane with each other; a battery and key 2 are connected in series with one coil and a telephone receiver 5 in the complementary loop of wire. When the coils are adjusted several yards apart, the "make and break" of the sending circuit by the key causes the electric energy to be transformed into curved magnetic lines which thread through the receiving coil producing in the latter an electromotive force proportional to the rate at which they link with it. Trowbridge believed that this *inductive method*, as it is termed, could be made to operate effectively between vessels separated by a distance of at least a mile.

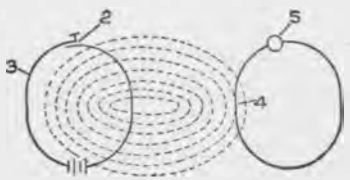
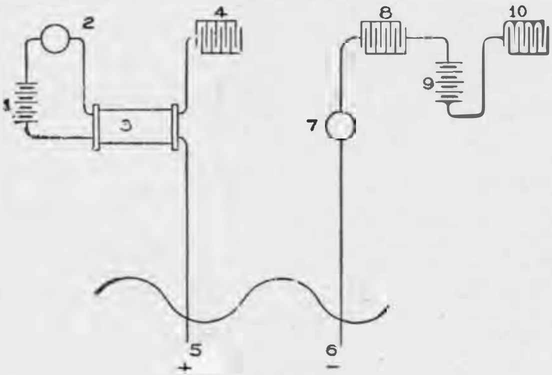


Fig. 2. Inductivity Method.

Electrostatic Method. A curious coincidence is now presented in the *electrostatic* method evolved (patented and experimented with by Dolbear, of Boston, in 1886) since it is an almost exact counterpart of that proposed by Silva in 1795, for the apparatus of the former is designed to fulfill the precise functions required by the hypothesis of the latter, that is, the charging of the earth at the sending and receiving stations to opposite signs. The sending instrument, indicated diagrammatically in Fig. 3, consisted of a small induction coil 3, the primary winding of which was connected with a battery 1, an interrupter, and a key 2, while the terminals of the secondary coil were connected with a condenser 4 and the earth 5, respectively; the receiver was formed of a condenser 10, one side being connected to a battery 9, which in turn



Electrostatic Method.

Fig. 3.

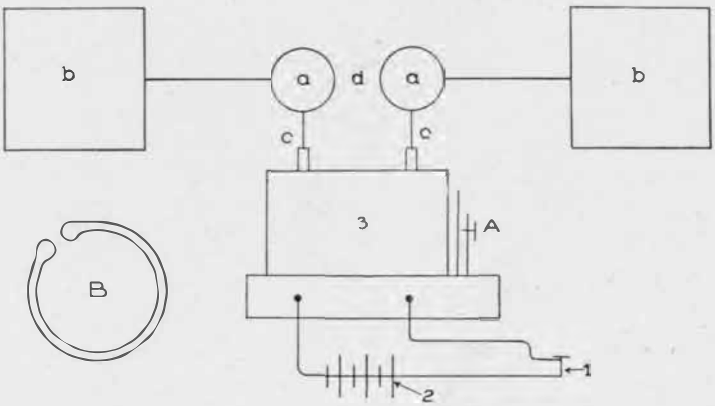
led to a second condenser 8, thence to a static telephone receiver 7, the terminal connecting to a plate 6 in the earth. Edison followed with a somewhat similar arrangement in 1891, except that he employed ærial wires with plates of metal at the top, which served as capacity areas, instead of the condensers described above. There is no authentic record of the performance of either of these devices.

Electric Wave Method. All the methods described above have their especial limitations, and these are so tightly drawn that none of them have ever approximated a utility of the slightest commercial importance; work, however, continued along these lines, but during the past fifty years an entirely new method has been unfolding, a method at once marvelous in conception, beautiful in theory, perfect in formation, and startling in its final results; this is the *electromagnetic wave method*.

The fundamental principles upon which this method is based may be said to have begun in 1678 when Huygens, a Dutch mathematician, conceived the hypothesis that all space not taken up by gross matter was filled with a highly attenuated subtle substance named ether, and by which he was enabled to account logically for all the phenomena of light.

Faraday, in 1845, not only believed in Huygen's luminiferous ether but demonstrated by experiment that electric and magnetic forces were propagated through the same medium. This physical evidence was resolved into a mighty theoretical system by Maxwell who determined mathematically the relations between all the varied phenomena presented by these different, yet allied, sciences.

The last link in the chain necessary to establish absolutely these great fundamental truths was supplied by Hertz, of Karlsruhe, Germany, in 1888, who succeeded in producing electromagnetic, or, as he termed them simply, electric waves, which followed every known law of light, such as rectilinear propagation, refraction, polarization, etc. The electric waves discovered by Hertz are, of course, much longer than those of light, and being much too long



Hertz's Electromagnetic Wave Method.

Fig. 4.

to affect the eye, they are invisible; every known test, however, only served to offer additional proof that the Hertzian waves are transverse vibrations in the ether, and that they are propagated through space at a velocity equal to that of light.

The apparatus Hertz employed in producing and receiving electric waves is shown in Fig. 4. The sending apparatus A comprises an induction coil 3 energized by a battery 2, and operated by a key 1; the high-tension terminals are connected to an oscillator formed of two brass spheres *a*, *a* attached to large metal sheets *b*, *b* by brass rods; this is the arrangement by which the waves were radiated. The spark-gap is shown at *d*. The receiver B is simply a loop of wire with the free ends brought nearly together, and when the waves impinged upon it, their presence was indicated by the passage of minute sparks in the gap formed between the ends.

Here then was a complete apparatus for fulfilling the conditions of signaling through space without wires; but many improvements were needed before an efficient system could be produced capable of operating on a commercial scale. For instance, the metal ring receiver of Hertz required too much energy to affect it at any great distance, but this defect was overcome by Branly, of Paris, who found,

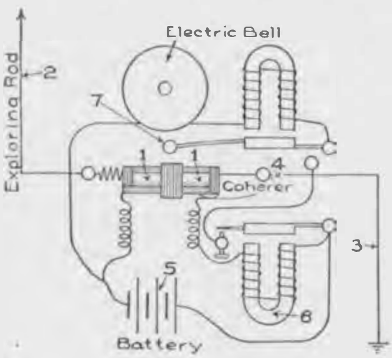


Fig. 5. Popoff's Receiver

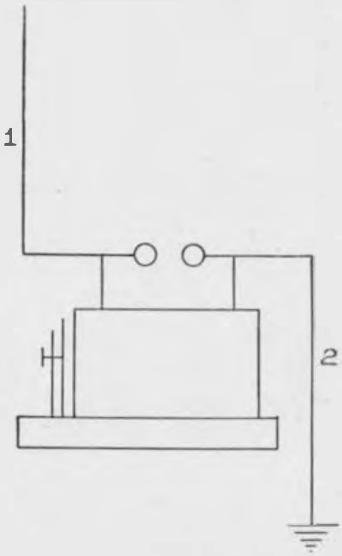


Fig. 6. Marconi's Transmitter.

in 1890, that metal filings enclosed in a tube, termed by him a *radio-conductor*, were marvelously sensitive to enfeebled electric waves impinging upon them. In 1895, Popoff, of Russia, combined with a *coherer* 1, as Branly's detector had been re-named, an electric bell, the hammer 7 of which also served as a tapper to de-cohere the filings, a sensitive relay 6 and a local battery 5, as illustrated in Fig. 5; one terminal of the coherer was connected to a rod 2 elevated in the air while the opposite terminal 3 led to the earth. This formed a self-acting receiver, but was used by him in the study of atmospheric electricity. The spark-gap is shown at 4.

This was the state of the art when Marconi, of Italy, in 1895 began his experiments with a view to long-distance transmission. In his earlier trials in Italy, the young man employed the induction coil and oscillator in transmitting, just as Hertz did before him, but later he ascertained that if one side of the oscillator was connected to a wire 1 suspended in the air, and the opposite side was connected to the earth 2, as in Fig. 6, the energy would be radiated in the form of electric waves to much greater distances than was possible with the simple oscillator designed by Hertz. The receiver used by Marconi in connection with his transmitter was very like that of Popoff except that he added a Morse register and adjusted the mechanism to imprint the received impulses in dots and dashes in accordance with the signals transmitted.

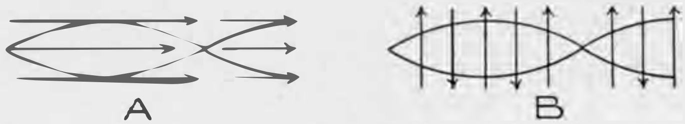
The results attained by Marconi bring the history of wireless telegraphy to the time of its commercial adoption in 1897. Since then there has been a multitude of workers, all of whom have bent their efforts to eliminating its defects, and these men and their work will find a place in the succeeding pages of this text.

PRINCIPLES.

Ether. The first principles upon which the theoretical structure of wireless telegraphy is based are identical to those evolved by Faraday and Maxwell to account for all the phenomena of light, since in either case the waves are electromagnetic in character and are transverse vibrations in and of the ether.

In accepting the hypothesis of an all-pervading substance, termed the electromagnetic medium, it is neither necessary to know its essential form nor its composition, for just as sound may be sent through the air without a knowledge of its constituent parts, so also may electric waves be propagated likewise through the ether. But if the laws of either sound or electric waves are to be deduced then some of the characteristics of the medium in which they are set up and through which they travel must be known, and in working out the system of sequences that governs the action of light, mathematicians come to conclude that ether is a highly attenuated substance, that it possesses elasticity and rigidity, that it has density and that it is incompressible. Thus it will be observed that ether is closely related to electricity yet it partakes of some of the properties of gross matter, and while Sir Oliver Lodge has pointed out that electricity may be a product of shearing the ether, J J. Thomson has done much to indicate that corpuscular matter is of etheric origin.

The constants of the ether have been determined empirically and its specific inductive capacity is taken at 1 which is expressed symbolically by the letter K, while its density is assumed to be about 936 one-sextillionths that of water and is represented by the Greek letter μ. Now μ divided by K equals the velocity of light and all other forms of electromagnetic energy or $\frac{\mu}{K} = 186{,}500$ miles per second.



Air Waves and Electric Waves.

Fig. 7.

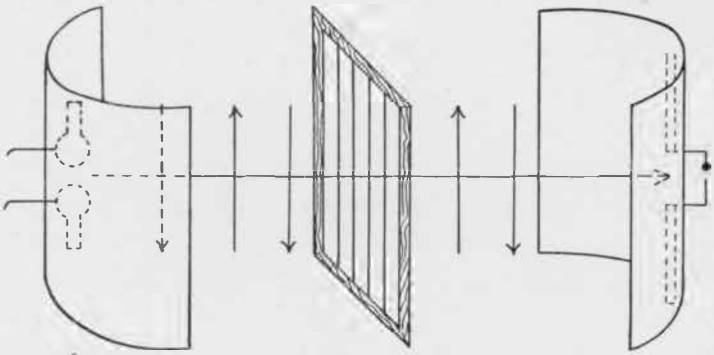
Electric Waves. Undulatory, or wave, motion through the air and that taking place in the ether are different in that the first consists of longitudinal thrusts due to one molecule of matter striking another, while in the latter the motion is caused by transverse vibrations taking place across the line of propagation due to polarized stresses in the ether as shown in Fig. 7, A and B respectively. *Electromagnetic*, or to use the common abbreviated term, *electric waves*, are, however, like sound waves in a number of limiting cases, as for instance, they may vary greatly in length and yet the speed at which they travel in their respective mediums remains constant; again, just as in air, waves of different lengths produce different tones when they impinge on the ear, waves in ether, of very short but varying lengths, reflect dissimilar colors, the violet being the shortest and the red the longest visible waves.

An electric wave a little longer than the red is invisible to the eye, but its effects may be felt in the form of radiant heat. Between the short, radiant heat waves and the long electric waves produced by the disruptive discharge of an electric spark there is a wide gap, yet they are identical except when their lengths are considered.

Because they are invisible and the senses of man incapable of perceiving them except by the aid of some exterior physical means, the existence of electric waves had not been proven by experiment until 1888, when Hertz demonstrated their characteristics, showed a method for producing them, and a simple means by which they could be detected and their effects observed.

Electric waves of whatever length are the result of charges of electricity in rapid motion; if the charge of an atom is set into vibration it will emit a very short wave length, say 271 ten-millionths of an inch which is that of red light, but if a pint Leyden jar is discharged its oscillations will send out waves 50 or 60 feet in length.

Electric Oscillations. Since all waves in ether are due to transverse vibrations they should follow the same physical laws,

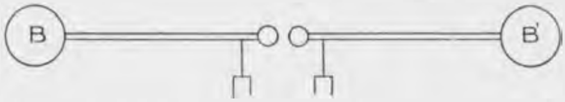


Polarized Electric Waves.

Fig. 8.

and to prove that the long electric waves were identical with those of light, Hertz reproduced all the known optical experiments; showing that waves from his oscillator traveled in straight lines, by reflecting them from the surfaces of metals; that they could be refracted, by passing them through huge prisms of pitch; he formed shadows by intercepting them with his own body and other objects; and finally he polarized them by means of a grid made of a number of parallel wires as shown in Fig. 8.

Disruptive Discharge. To set into vibration the electric charge of an atom for the purpose of producing light, it is usual to employ heat, but to obtain long electric waves for experimental purposes or for wireless telegraphy there is only one method known to science and that is by discharging a charged Leyden jar or other oscillator formed of opposite metal conductors B, B' and separated by a spark-gap as shown in Fig. 9; this form of oscillator is



Open Circuit Oscillator.

Fig. 9.

charged by an induction coil or other high-tension apparatus. When the spark takes place, the opposite sides or arms of the oscillator discharge into each other, thus equalizing their difference of potential through the spark or disruptive discharge.

The moment the spark occurs, the static charge of the oscillator is changed into kinetic energy which surges through the system to and fro, like a straight steel spring suddenly released; but while the energy of a spring is damped out in the making of air waves, the electric oscillations are transformed into electric waves in the ether, but in both cases the energy decreases in geometric progression from maxima to zero as described in the curve, Fig. 10.

Fig. 10. Electric Oscillations.

For this reason the waves can be emitted only periodically, and before another train of waves can be started, the oscillator must be recharged, and this requires time. The charging is done automatically by having the terminals of an induction coil connected with the arms of the oscillator so that as soon as the oscillatory currents set up by the spark have damped out their energy in electric waves, the high-tension current generated by the coil will instantly recharge the oscillator to its maximum capacity, when it will again break down the thin film of air and the cycle of operations will be repeated.

To determine the length of an electric wave, it is necessary to know not only its velocity, which has been previously calculated, but also the period of oscillation of the system radiating the waves; the latter depends upon the constants of the oscillator circuit, that is, its capacity C, its inductance L, and its resistance R. These factors are in turn governed by its length and other dimensions, and the time of oscillation T may be found by the formula $T = 2 R \sqrt{LC}$; the resistance may be considered negligible in a simple open circuit where oscillations are of sufficient frequency to send out electric waves. The length of the wave is easily found by dividing the velocity v by the number of waves n, or $\frac{v}{n}$ = the wave length.

Electric waves emitted by a simple oscillator of the Hertz type give rise to free spherical waves in space, and the writer has ever advocated the theory that this is the form of waves radiated by the ærial wire and earthed-oscillator system of a wireless telegraph transmitter, while Blondel, Taylor, and Fessenden have promulgated a theory in which the waves are assumed to be hemispherical or half-waves which slide over the surface of the earth or sea; the illustrations, Fig. 11, A and B respectively, show graphically these two view-points.

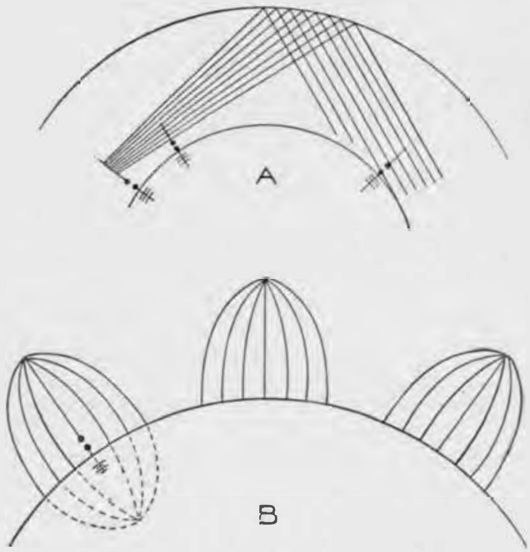


Fig. 11. Electric Wave Propagation.

Having ascertained the process by which low-voltage direct currents are transformed into currents of high frequency and potential, and how these oscillations radiate their energy into space in the form of electric waves, the final fundamental principles involve their reception and indication. While all insulating materials are transparent to electric waves, conductors of electricity have the property of intercepting them, but this does not imply that they are forever lost, for conversely, they follow the well-known laws for the conservation of energy, and the waves are simply transformed into another form of energy, or back again into electric oscillating currents, as the heat in steam is converted into mechanical motion.

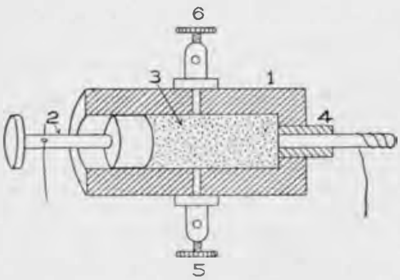


Fig. 12 Branly's Radio-Conductor.

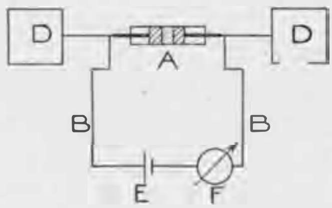


Fig. 13. Open Circuit Resonator.

The currents set up in a conductor of a receiving circuit, termed a *resonator*, have a rate of oscillation exactly equal to that of the radiator at the sending station. In Hertz's experiments, a circlet of wire was used as a receiver, or resonator, and when the oscillations raised the potential to a critical point the tension broke down the air and a minute spark passed.

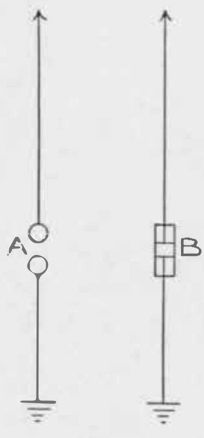


Fig. 14.

Branly introduced a little tube 1, filled with filings 3, see Fig. 12, termed a radio-conductor, in the resonator circuit that is between two arms made of metal and similar to the oscillator except that the tube of metal filings took the place of the air-gap. 2 and 4 represent conductor plugs, and 5 and 6 binding posts. When electric oscillations are set up in the resonator by electric waves impinging upon it, the oscillatory current causes the filings of the *coherer*, as Branly's filings detector has come to be universally called, to be drawn more closely into contact, and the resistance which is normally high, is thus very greatly diminished

The easiest and simplest method for the detection of these changes in resistance is to connect in series with the coherer A, a single cell E, and a galvanometer, or a telephone receiver F, as in Fig 13; D and D represent the capacity plates and B, B the internal circuit. It is obvious that when the filings cohere, the current from the cell will readily flow through the circuit including the galvanometer, its needle will then be deflected and it will so continue until the filings are restored to their normally high resistance, which condition may be easily attained by merely tapping the tube with a pencil; in practice, the decohesion of the particles is usually effected automatically by an electro-mechanical device.

In commercial wireless telegraphy, the ærial wire at the sending station is connected with the earth through the medium of a spark-gap, as A in Fig. 14, which constitutes the circuit wherein the current oscillates. At the receiving station, the coherer is connected to the lower terminal of the vertical wire and to the free end of the wire leading to the earth, as indicated at B, forming the resonator.

Marconi ascertained that the energy of the waves did not diminish in intensity when the distance was increased if the length

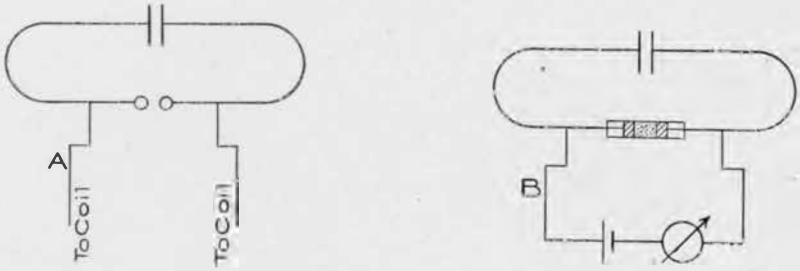


Fig. 15.

of the ærial wires were increased as the square of the distance, that is, by doubling the height of the wires the waves would be transmitted to four times the distance, the initial energy remaining the same. These are the first principles of the action of electric waves and the operation of the earliest and most simple forms of wireless telegraph systems, while those of a later and more complex nature depend on electrical resonance and electro-mechanics.

It has been previously shown that the length of an electric wave depended upon the coefficients of the oscillator, and it has also been pointed out that a resonator in the field of force would have oscillations produced in it by the impinging waves.

Resonance. Now it is well known that when an oscillator and a resonator have exactly the same electrical dimensions, that is, inductance, capacity, and resistance, the currents set up in the resonator will be much stronger than where the circuits are not in resonance with each other. By applying the laws of resonance to wireless telegraphy, inventors have striven to produce the same conditions on a commercial scale that have been obtained in the laboratory in order to provide a method capable of signaling selectively.

The oscillators and resonators previously described were of the *open-circuit* type, having two oppositely disposed arms; but for resonance effects *closed-circuit* oscillators and resonators, illustrated diagrammatically in Fig. 15, at A and B respectively, give the maximum results. Conversely, open-circuit oscillators are the best radiators of electric waves, damping out the energy in two or three swings while the closed-circuit type permits the current to oscillate for a long period of time and consequently very feeble electric waves are emitted. Hence wireless telegraphy systems with open circuits give the best results over long distances, but as these are co-resonant, in virtue of the capacity of the earth with which they are connected, every receiver is in syntony with every transmitter, and therefore they have no individual selective properties. The efforts to combine open and closed circuits to obtain the advantages of long-distance transmission and selective signaling has led to many ingenious relations and the production of several syntonic systems.

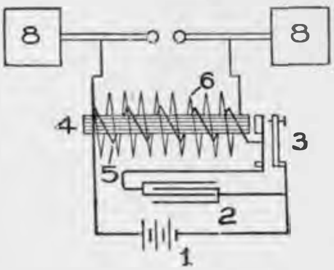


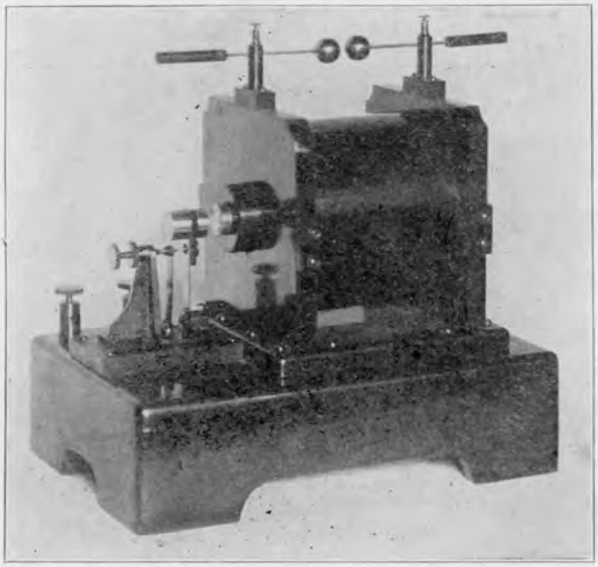
Fig. 16. Induction Coil and Oscillator.

APPARATUS.

The apparatus comprising the transmitter consists of a source of electromotive force, a battery or dynamo, a key, an induction coil or transformer, and an oscillator. The appliances forming a receiver of the simplest type include a wave detector, a cell, a telephone receiver, and a resonator; in the earlier and more complex systems, a relay, a tapper, and a Morse register were added.

Induction Coil. There are two methods of transforming low-potential into high-potential currents. The first is by means of an *induction coil* and the second is by using a *transformer*. The term induction coil differentiates this apparatus from that known as a transformer; the former being supplied with an interrupter and a condenser and energized by a low-voltage direct current, while the latter has neither of the devices just cited and is operated by a low-voltage alternating current.

The induction coil, Fig. 16, is made up of an iron core 4, formed of a number of soft iron wires having wound around them



Induction Coil.

Fig. 17.

two layers of heavy wire 5, called the *primary coil* or *inductor*. One end of the primary leads direct to the battery 1, the other connecting with an interrupter 3, a simple mechanism for automatically making and breaking the current, which is in turn connected to the opposite pole of the generator. Around the "make and break" a condenser 2 is connected in shunt, assuming the contacts of the interrupter to be closed, but when open the condenser is in series with the primary coil.

Outside the primary coil and well insulated from it is the *secondary* coil 6, built up of several thousand feet of very fine wire and thoroughly insulated with a compound of resin and beeswax. The terminals of the secondary connect to the opposite arms 8, 8 of the oscillator. In operation, when the primary coil is energized by the current, the core becomes magnetized and magnetic flux surrounds the coil in a direction paralleling its axis. This causes a current to be induced in one direction in the secondary. When the interrupter breaks the circuit, a current is induced in the opposite direction; this is repeated automatically several hundred times per minute resulting in a high-tension alternating-current flow at the terminals of the secondary coil and which is utilized for charging the oscillator. Fig. 17 is a photographic illustration of an induction coil.

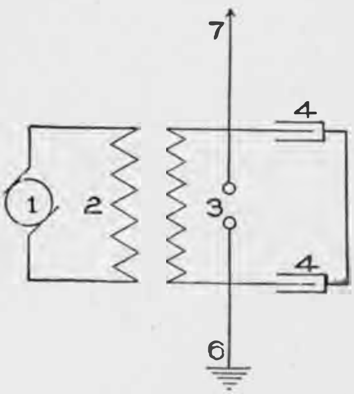
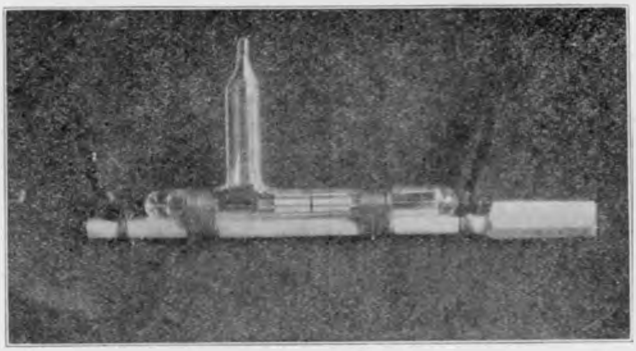


Fig. 18. Transformer Transmitter.

Transformer. In a later method, shown in Fig. 18, the primary winding 2 of an ordinary commercial oil transformer is connected



Marconi Coherer.

Fig. 20.

to the terminals of an alternating-current generator 1, of say, 60 cycles and 500 volts. The ends of the secondary of the coil 3 are joined to a battery of Leyden jars 4, 4. When in action, the

FESSENDEN WIRELESS TELEGRAPH STATION.

National Electric Signaling Company.

reversals of the current in the primary of the transformer induce alternating currents in the secondary coil having the same period but enormously increased potential, the transformer giving about

Fig. 19. Wireless Telegraph Key.

25,000 volts at the secondary terminals. This low-frequency, high-potential current charges the Leyden jars to the limit of their capacity, when they discharge through the spark-gap of the oscillator. 6 is the earthed terminal and 7 the aerial wire.

Keys. In order to break up the current arbitrarily into dots and dashes, a telegraph key is interposed in the primary circuit; the keys usually employed are constructed like an ordinary telegraph key, but are very much larger, like the one in Fig. 19, as the currents to be broken are often in excess of 746 watts or one electrical horse-power. Another form of key, designed to be operated with the rapidity of the ordinary Morse key, is constructed so that the heavy current is broken under oil.

The spark-gap, dividing the ærial wire and the earthed terminal is usually formed of two spheres or discs so that the length of the disruptive discharge may be regulated at will.

Wave Detectors. Of the receiving devices the wave detectors are the most important. These comprise two general classes; those of the first class are *voltage-operated* and are of the coherer type, in which the resistance is lowered by the potential of the oscillations, and the anti-coherer type in which the resistance is increased by the oscillations. Those of the second class are *current-operated* detectors where the current strength of the oscillations varies the resistance of a fine wire or liquid through heat losses by radiation.

A coherer of the filings type is shown in Fig. 20; two silver conductor plugs with platinum wire terminals are forced into a piece of glass tubing leaving a space or pocket for the

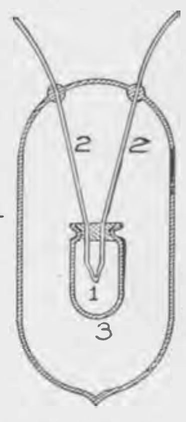


Fig. 21. Fessenden Barretter.

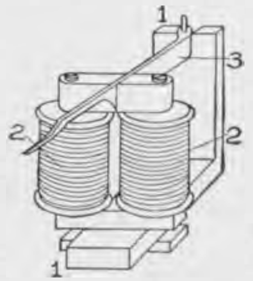
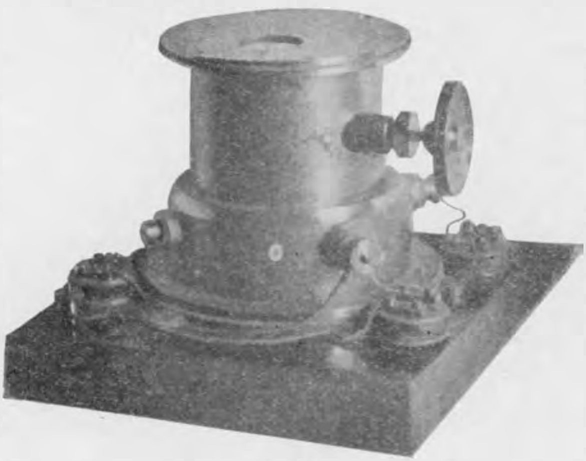


Fig. 22. Polarized Relay.

filings—made with a coarse file from nickel and silver in the proportions of 90 per cent of the former and 10 per cent of the latter; the tube is then adjusted, the air is exhausted with a mercury pump, and the tip sealed off. *Anti-coherers* are made by substituting oxide of lead for the ordinary filings between the conductor plugs; the current from the local cell causes minute threads of metal to be built up between the plugs by electrolysis, and these are disrupted by the electric oscillations. *Auto-coherers* are those that need no tapping to bring them back to their normal resistance after the effects of cohesion, but are restored automatically in virtue of their inherent properties.

A barretter or current-operated wave detector is illustrated in Fig. 21; it is made of a little loop of silver wire having a diameter of .002 inch with a core of platinum wire 1 drawn down to .00006 inch in diameter; the tip of the silver loop is then dissolved away exposing the platinum filament; this done, the ends of the loop are attached to the leading-in wires 2, 2 sealed in a glass bulb which is finally enclosed in a silver case. The silver shell is shown at 3 and the glass globe at 4. A new form of barretter employs a very small column of nitric acid and a minute platinum wire immersed in the liquid so that the resistance of the latter is concentrated closely to the point. Anti- and auto-coherers and barretters can be used only in connection with a telephone receiver,



Marconi Polarized Relay.

Fig. 23.

for their resistance variations are too limited to permit the relay to be actuated; the filings coherer is the only type of detector known that can be employed in combination with a relay.

Relays. Of relays there are several forms, but the *polarized relay*, shown in Fig. 22, is the only one sensitive enough to be used in conjunction with a coherer for long-distance work. A polarized relay is provided with a permanently magnetized armature 3 instead of the soft iron one of the ordinary instrument; it has two magnets, one an electromagnet 2, 2 and the other a permanent magnet 1, 1; by this arrangement, when no current is passing through the coils of the electromagnet, the poles will be north; but when the current flows, one of the poles is more strongly magnetized while the other changes its polarity to south. There are several modifications of the polarized relay, but their principles of operation are the same. Fig. 23 shows the type used in wireless-telegraph receivers.

De-Coherer. Next in importance is the tapper, or de-coherer, for restoring the filings after the oscillating current has cohered them. The construction of a tapper is much like that of the ordinary electric bell with an automatic contact breaker; but different from the latter in that the hammer of the tapper has a very low time constant so that its vibrations can be very rapid. Such a tapper is shown in Fig. 24, and is, it will be observed, provided with a device for supporting and adjusting the coherer so that the strength of the stroke of the hammer may be varied at will.

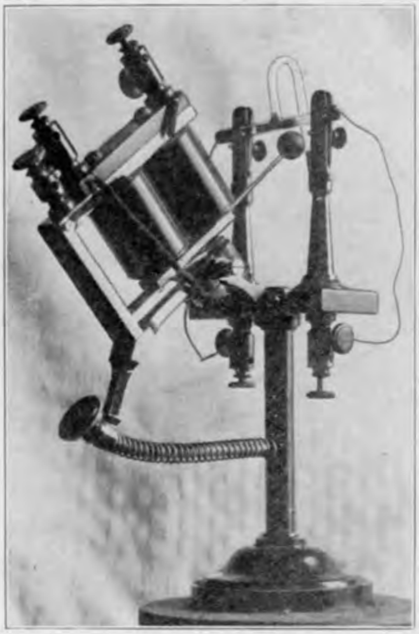
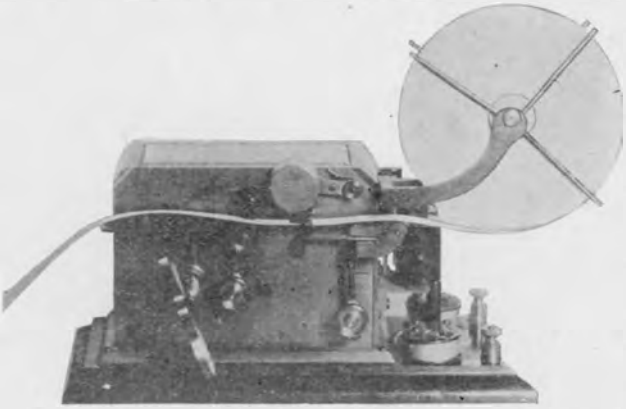


Fig. 24. Guarini Tapper.

There are several instruments for translating the received impulses into readable Morse, as for instance, the galvanometer, the telephone receiver, the ordinary sounder and the Morse register. The three former appliances are so well known that they need not be described here. The register is employed where it is desirable to have a permanent record of the received message, and a general idea may be gained of its construction and operation by referring to Fig. 25.

Register. The register is an electro-mechanical apparatus comprising a spring motor, the purpose of which is to draw a tape of paper under an inked disc operated by an electromagnet.



Morse Register.

Fig. 25.

When a current is passing through the coils of the electromagnet, the inked disc, which is attached to the armature, is drawn into contact with the paper and held there until the current ceases; in this way the dot and dash code is formed and imprinted on the tape.

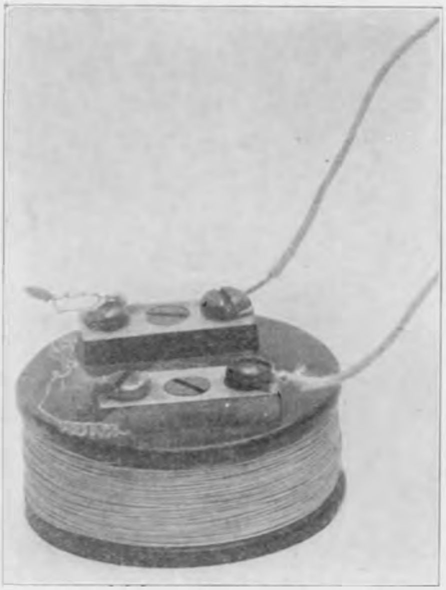
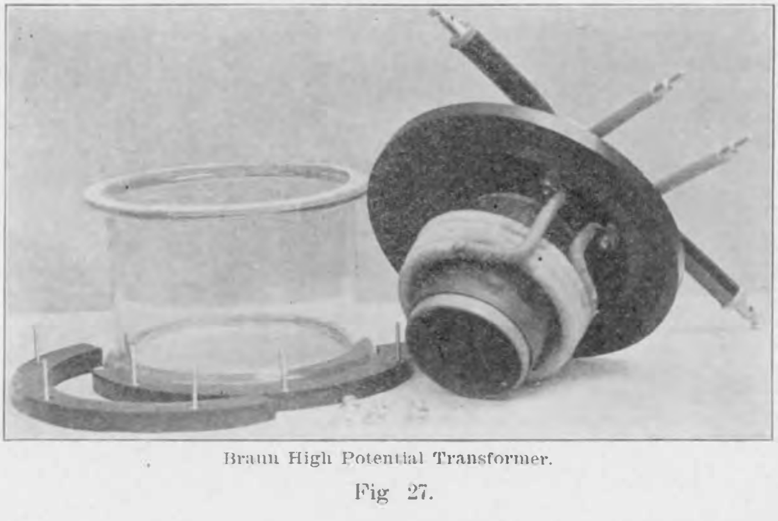


Fig. 26. Choking Coil.

The above appliances are the principal ones making up the ordinary wireless telegraph systems, but there are a number of other and minor devices utilized to render more accurate the working of the instruments. One of these is the *choking coil*, made of a long, fine insulated wire doubled back on itself and then wound on a wooden spool as shown in Fig. 26; these coils are interposed in the local circuits of the receiver to cut off high-frequency currents which may be set up by sparking, either in the coherer or between the relay contacts.

Oscillation Transformers are used in many systems of recent design; these are constructed for stepping up or down high-frequency and high-potential electric oscillations, and are employed in both the sending and the receiving circuits. The transmitting transformers have an inductor or primary of three or four turns of heavy wire wound *outside* the secondary coil which is formed of thirty or forty turns of fine wire, when the coils are then immersed in oil; two views of a typical transformer are illustrated in



Braun High Potential Transformer.

Fig 27.

Fig. 27. Smaller transformers are often employed in the receiving circuits, and consist of simply a primary and a secondary coil insulated in the usual manner.

Inductance coils and *condensers* are also largely used in wireless telegraph practice for the purpose of increasing the inductance and capacity of the oscillators and therefore the waves emitted by them. They are also useful for tuning a closed-circuit to an open-circuit as well as to obtain resonance between the transmitter and receiver. Inductance coils are formed of a large number of turns of heavy wire with sliding contacts so that any desired value of inductance may be procured. Condensers for providing suitable capacities can be made up of Leyden jars or metal sheets immersed in oil where high tensions are employed, but in receiving circuits, those of the ordinary mica type are used. Finally where detectors of the coherer type are utilized a metal case is provided which encloses not only the coherer but the relay, tapper, and local cells leaving the register alone exposed. The object of the screening box is to protect the delicate and sensitive instruments from the powerful oscillations of the transmitter in the immediate vicinity.

With an understanding of the subsidiary apparatus comprising the component parts of transmitters and receivers and the principles involved, it is now easy to follow the intricacies of the various systems that complete the art of wireless telegraphy.

SYSTEMS.

The many different systems for sending messages through space without wires may be classified under two general heads, namely, those designed without regard to selectivity, and those where electrical resonance has been brought to bear in order to prevent interference. Those of the first class are termed *non-syntonic* and those of the second class *syntonic* systems.

Marconi. *First form.* The first complete system of wireless telegraphy was conceived and patented by William Marconi, who, by employing greater power, larger radiating surfaces and improving its details, was enabled to increase its effective range from 300 feet to 2,000 miles. His first apparatus was simply an open-circuit apparatus of the non-syntonic type as a reference to the diagram Fig. 28, will show.

The transmitter A includes an induction coil 1, energized by a battery 2, the current being broken up into the Morse code by the key 3; the coil is equipped with a spring interrupter 4; the terminals of the secondary are connected to either side of the spark-gap 5, which with the ærial wire 6 and the earthed terminal 7, forms the oscillator system. The receiver B is made up of a coherer 1, the polarized relay 2, and the cell 3, all of which are connected in series and comprise the first *internal circuit*. The second internal circuit includes the contact points of the relay 2, the Morse register 4, the battery 5, and the tapper 6; the tapper

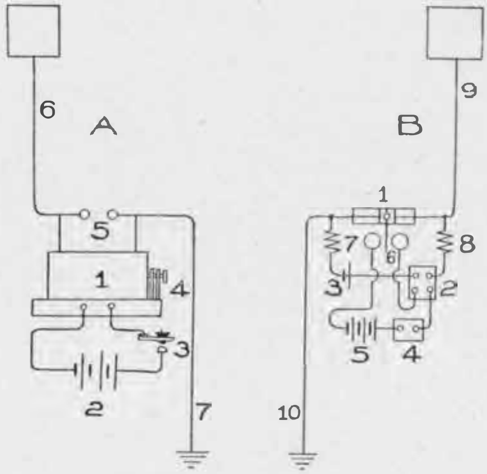
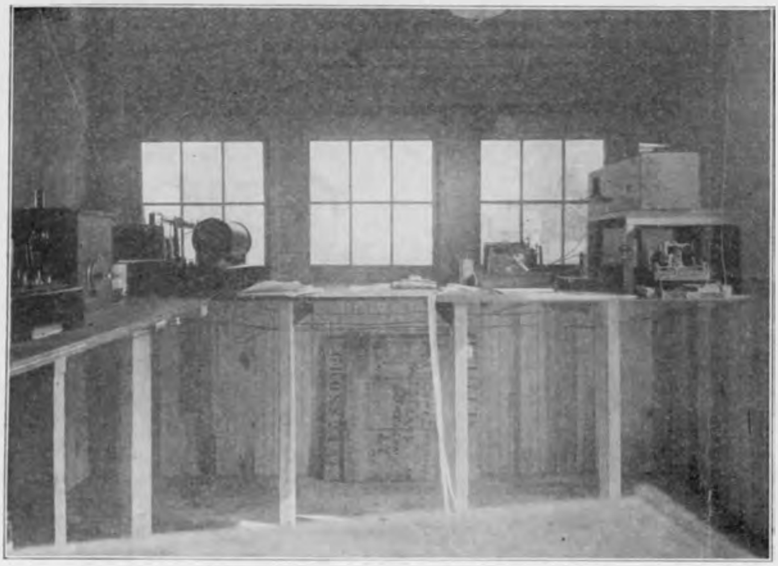


Diagram of Original Marconi Transmitter and Receiver.

Fig. 28.

and register may be in series or parallel; the ærial wire 9 and the earthed terminal 10 form the resonator. Choking coils 7 and 8 are placed in the first internal circuit between the coherer and the relay to prevent oscillations from the resonator from wasting their energy in the relay coils, as well as to prevent those originating at the contacts of the relay from acting on the coherer. To the free ends of the ærial wires were attached large sheets of metal termed capacity areas, but these are no longer deemed necessary. A photograph of a Marconi station at Babylon, Long Island, is given in Fig. 29.

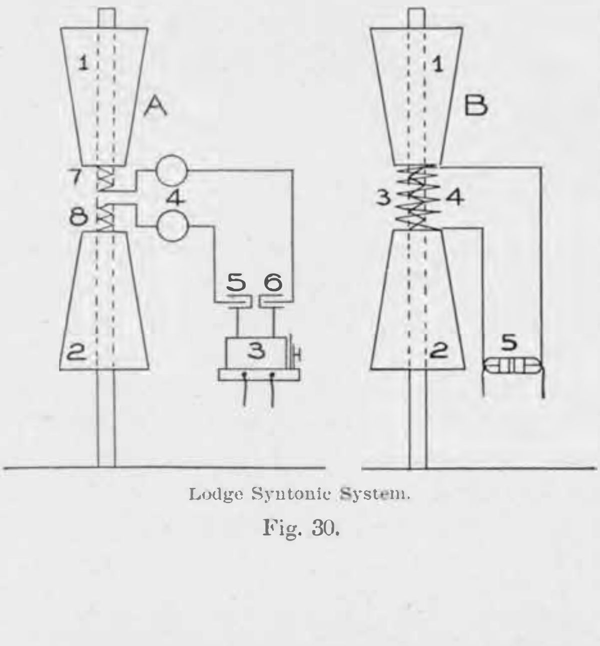
Lodge. To Sir Oliver Lodge is due the credit of having evolved the first syntonic electric-wave apparatus based on the laws of resonance, and since nearly all the succeeding systems utilize these principles a brief review of his arrangement may prove use-



Marconi Wireless Telegraph System.

Fig. 29.

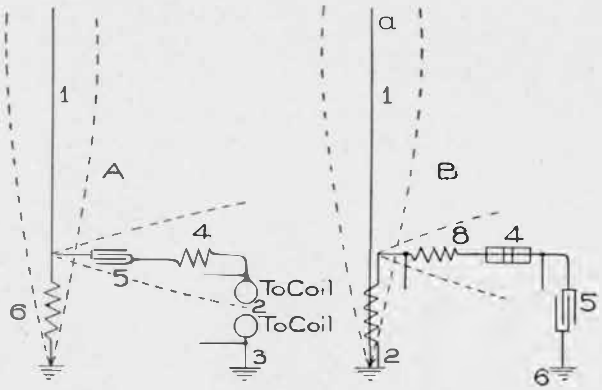
ful. In this system, instead of the usual aerial and earth wires, two conical metal capacity areas are substituted; in Fig. 30, A, 1, and 2 represent the areas which are charged by an induction coil



Lodge Syntonic System.

Fig. 30.

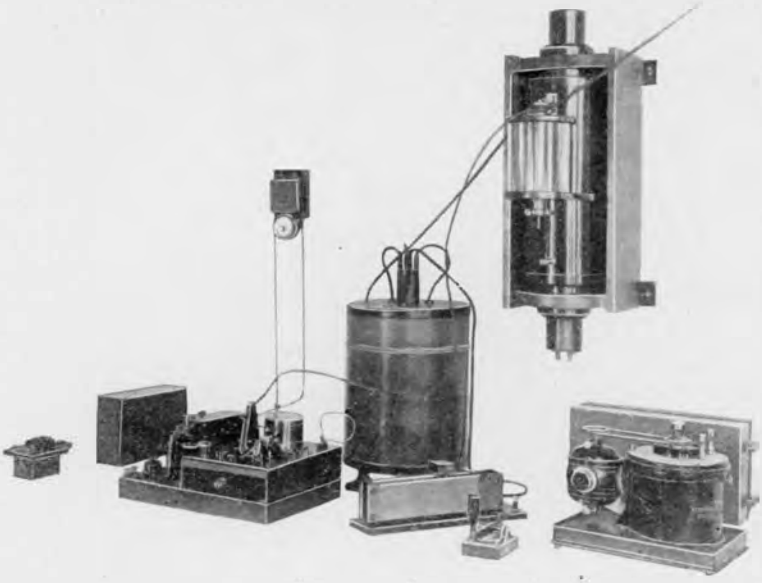
3 and which discharge through the spark-gap 4; the value of capacity can be changed by means of the adjustable condensers 5 and 6; the values of inductance are also made variable by the coils 7 and 8; the resistance of the circuit is negligible; it is obvious that a wave of predetermined length may now be obtained since it depends on the period of oscillation and this on the inductance and capacity of the circuit. The capacity areas are insulated from the post which supports them. The receiver B is formed of two similar capacity areas 1 and 2, and these are connected through the primary of an oscillation transformer 3, the secondary of which 4 leads to the coherer 5; the relay, tapper, and register are not shown but operate as previously described.



Diagrammatic View of Slaby-Arco Multiple-Tuned Wireless-Telegraph Transmitter and Receiver.

Fig. 31.

The Slaby-Arco System, of German manufacture, is now extensively used in the United States Navy, and though retaining the ærial wires and earthed terminals it is based on certain resonance phenomena as will be seen. When an oscillation is set up in a wire, it will emit a wave four times its own length; if the wire is connected directly to the earth, as shown in Fig. 31, the greatest amplitude will be at the free end of the wire while the nodal point will be at the earthed end as indicated by the dotted lines. If, in the transmitter A, the earthed radiating wire 1 is connected to the spark-gap 2 and to the earth 3 through the inductance coil 4 and the condenser 5, then a combination of an open and a closed circuit is formed, since the earth serves to close the circuit containing the spark-gap. Assuming that the inductance 4 and the capacity 5 is equal to that of the wire 6, then oscillations set up in the former will be impressed upon the latter which will radiate the energy in electric waves. In the receiver B similar conditions prevail; 1 is the receiving ærial wire or *antenna*, the oscillation having its greatest loop at *a*, 2 is the nodal point forming an open-circuit resonator; a closed resonator circuit is formed by the inductance 8, the coherer 4, condenser 5, and the earth 6; the point of greatest amplitude of the oscillations is arranged to correspond with the



Slaby-Arco System.

Fig. 32.

coherer which receives the maximum potential as indicated in the dotted lines. A photograph of the complete system is shown in Fig. 32.

Marconi. *Second form.* In seeking a solution for the problem of selectivity, Marconi produced a second system in which he eliminated the ærial wire, as in Lodge's scheme, but since grounded terminals were essential to long-distance transmissions, he retained these features. Fig. 33 is a diagrammatic view of the arrangement; the oscillator and resonator are compound, that is, each is of the nature of an open and a closed circuit. The transmitter A shows two concentric cylinders 1 and 2, separated by an air space and forming in reality a huge Leyden jar. The inner cylinder leads to earth and is also connected to the outer cylinder through the spark-gap 4 and the inductance coil 5. The receiver B has a similar cylinder 1 and 2; the outer is connected to the inner through the primary of a small oscillation-transformer 4 and inductance 5; the coherer 6 is connected to the secondary coil thus forming another closed circuit. These cylinders do not radiate their energy in two or three swings, yet the oscillations are not sustained to such a point as to enfeeble the emitted waves; when syntonized to each other, selectivity may be obtained within certain limits.

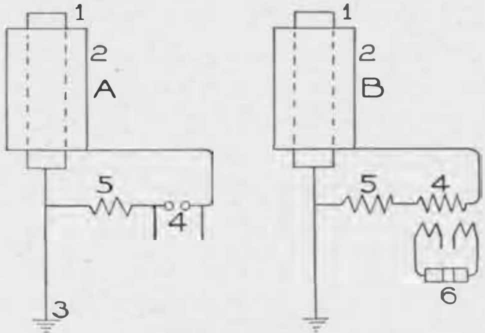


Fig. 33. Diagram of Marconi Selective Wireless-Telegraph System.

Braun-Siemens and Halske. One of the best theoretical syntonic systems is the Braun-Siemens and Halske of Germany. Oppositely disposed to the one just described, Dr. Braun has retained the ærial wires, but discarded the earthed terminals. The arrangement is shown graphically in Fig. 34. The fact that the ærial wire is one-fourth the length of the emitted wave, that the oscillations in one circuit can be transformed into another circuit, and that a closed circuit is a persistent oscillator while an open circuit is a strong radiator led to the design of the following apparatus:

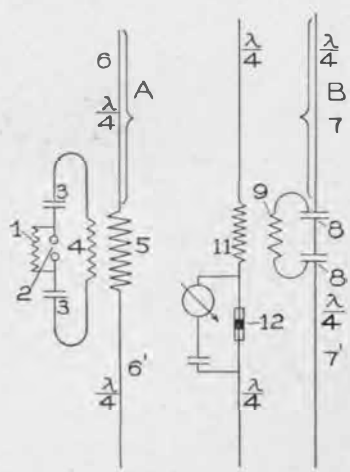
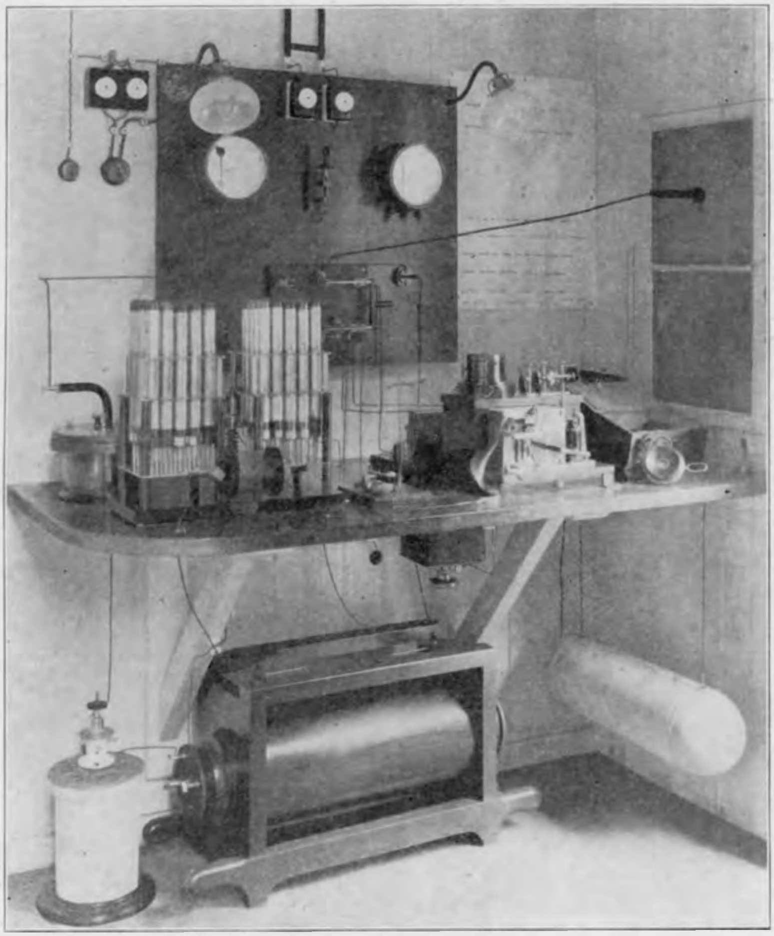
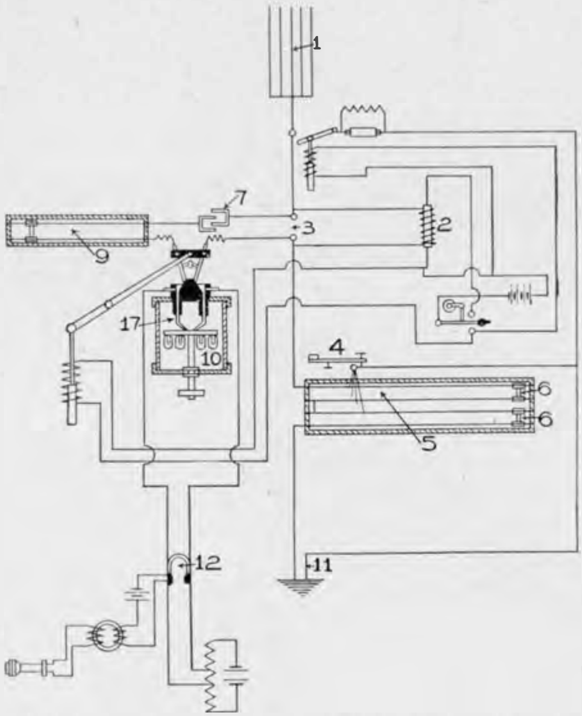


Fig. 34. Schematic Arrangement of Braun's Wireless-Telegraph System.



Braun Resonance System.
Fig. 35.

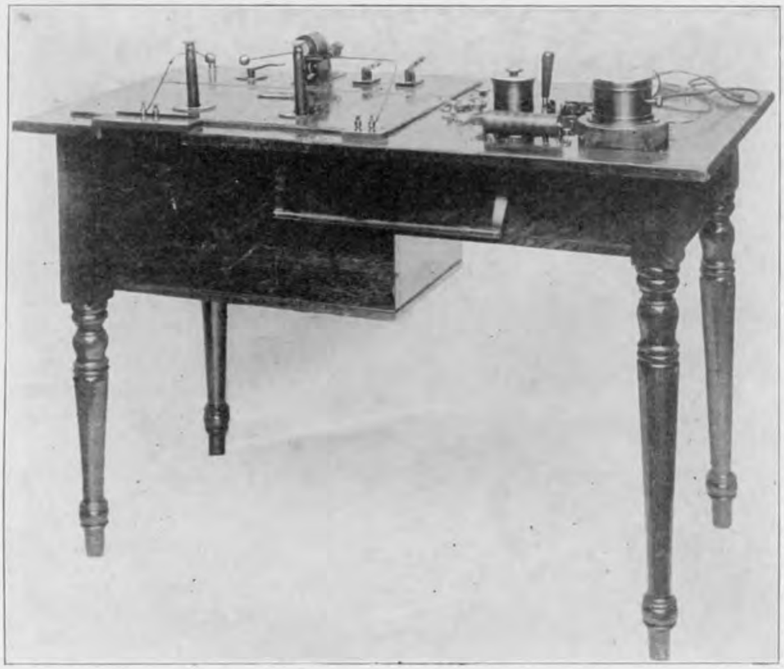
In the transmitter A, the secondary of an induction coil 1, charges the oscillator system of which the spark-gap 2, the condensers 3 3, and the primary 4 of a high-tension transformer are the complement; the transformer is shown in Fig. 27. The secondary 5 of the transformer connects with the ærial radiating wire 6, while the lower wire 6′ is made equal in length or it may be an inductance coil and capacity equal to that of the ærial wire. The receiver B has a similar ærial wire one fourth $\left(\frac{\lambda}{4}\right)$ the length of the received wave length connected with a closed resonator circuit formed of the condensers 8, 8 and the primary of a small oscillation transformer 9; the antenna 7 is balanced by an equal amount of capacity and inductance at its lower end 7′; the coherer 12 is placed in one arm of an open-circuit resonator; the secondary 11, of the transformer connecting with an opposite arm of equal electrical dimensions, completes the apparatus. Fig. 35 is a photographic reproduction of the Braun-Siemens and Halske system.



Fessenden Combined Sending and Receiving Apparatus.

Fig. 36.

Fessenden. An American system designed by Reginald A. Fessenden is shown in Fig. 36; it contains several novel features, as the use of a current-operated wave detector, invented by Prof. Fessenden and termed by him a barretter. The tuning of the circuits is accomplished by a grid formed of wires immersed in oil that gives a variable capacity and inductance without the use of



Fessenden Tuned System.

Fig. 37.

coils or condensers. By means of sliding contacts on the wires, the open-circuit oscillator may be tuned to the closed-circuit system so that both have exactly the same period.

By referring to the diagram the arrangement will become clear. In this drawing the transmitter and receiver are combined as they are in practice, since the same ærial and earth wires serve for sending and indicating the waves. The ærial wire 1 is supplied with energy from the induction coil 2 through the spark-gap 3; one side of the gap leads to the key 4, making connection with the tuning grid wires 5; these can be adjusted by the sliding contacts 6, 6 finally leading to the earth at 11. The receiving devices comprise a condenser 7 and a tuning grid 9 which connects with the barretter 10 through a holder containing a number of them at 17, an electromagnet automatically breaking the circuit in which they are placed by the operation of the induction coil; the resonator circuit is completed by antenna 1 and the earth 11; the variation

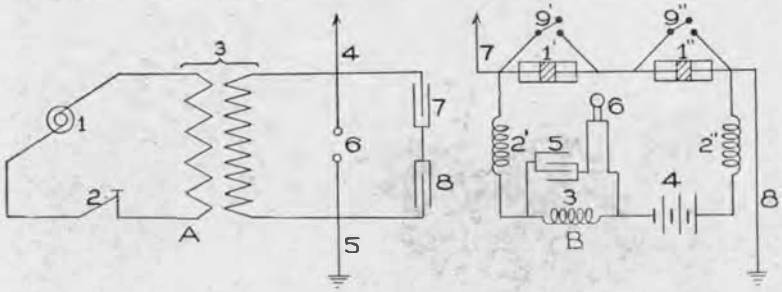
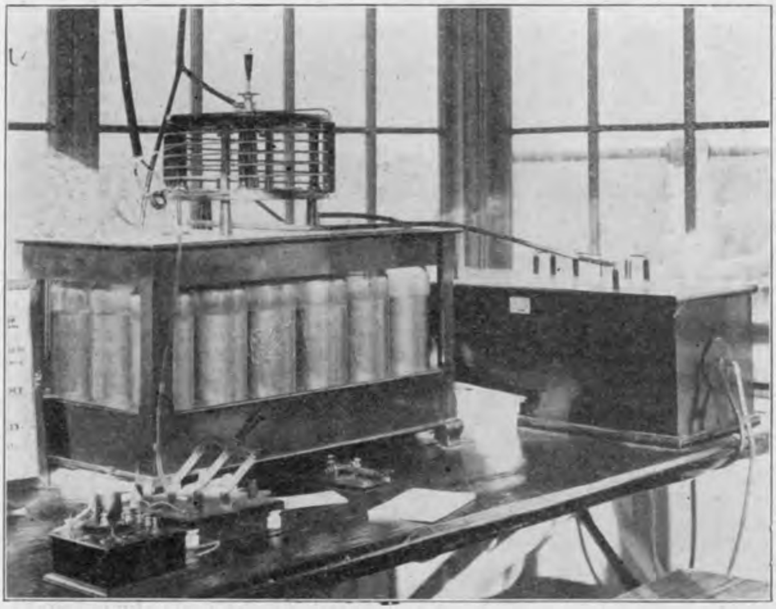


Diagram of DeForest Wireless-Telegraph System.

Fig. 38.

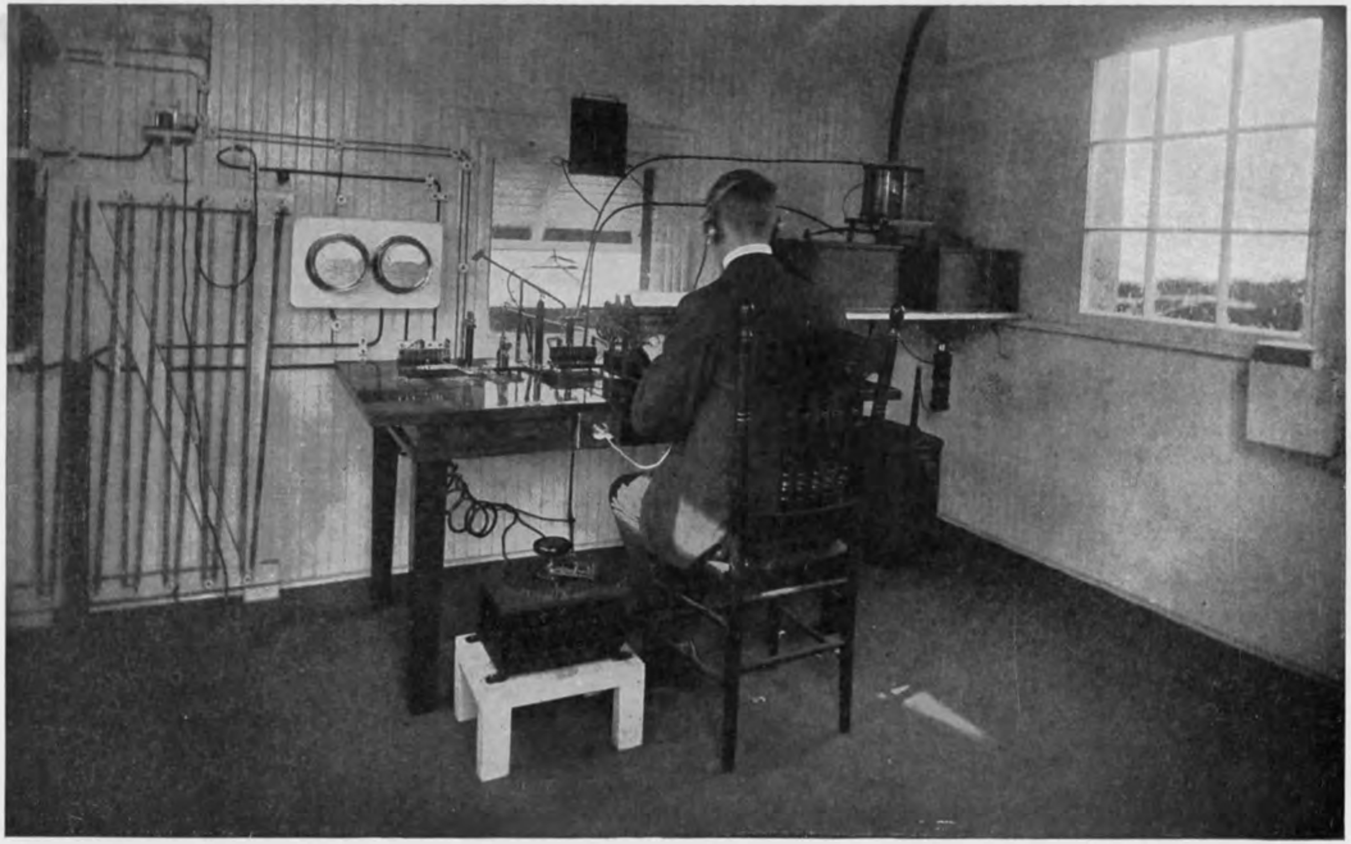
of the current is read by means of a telephone receiver 12. The apparatus is very compact as Fig. 37 shows, it is rapid in operation and accurate in its translations.

American De Forest. Another system using the telephone receiver as a means of indication is the American De Forest. This was the first commercial system to employ an alternating-current generator and an oil transformer to charge the oscillator system.



DeForest System Transmitter.

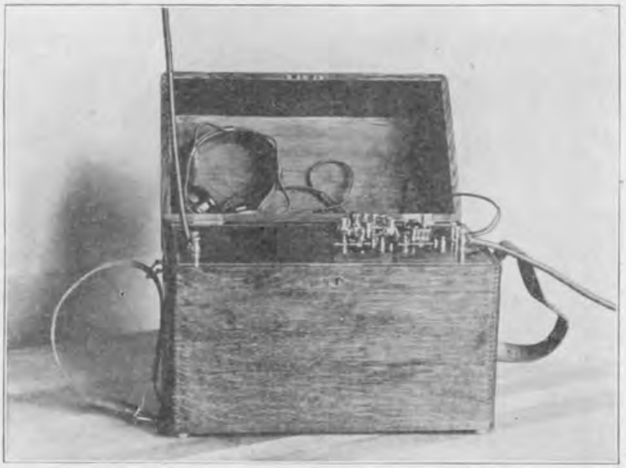
Fig. 39.



INTERIOR STANDARD FESSENDEN 250-MILE LAND STATION.

National Electric Signaling Company.

The transmitter A, Fig. 38, includes an alternating-current generator 1, an ordinary Morse key 2, with contacts breaking under oil, and a transformer 3. The ærial wire 4 and earthed wire 5 form a simple open-circuit oscillator through the spark-gap 6; this system is supplied with energy by the condensers 7 and 8 which are charged by the secondary of the transformer. The receiver in its simplest form comprises a self-restoring detector invented by Dr. De Forest and E. H. Smythe, called an *electrolytic responder*—previously described under "Principles"—a cell and a telephone receiver. In practice, it takes on the form shown at B; two responders 1', 1" are connected with the ærial wire and earth; the



DeForest Receiver.

Fig. 40.

internal circuit includes the responders 1', 1", the choke coils 2', 2", a resistance of 5,000 ohms 3, battery 4, condenser 5, telephone receiver 6, antenna 7, ground 8, and shunt switches 9', 9". This system has met with favor at home and abroad due largely to its simplicity and efficiency. Fig. 39 illustrates the transmitter and Fig. 40 the receiver.

Branly-Popp. Especial interest is attached to the Branly-Popp system in virtue of the fact that Prof. Branly is the original inventor of the coherer. The chief feature of the newly-designed apparatus is a tripod coherer and the elimination of the regulation tapping device. Fig. 41 is a diagram of the connections and Fig. 42 shows the apparatus. The transmitter is of the usual induction-coil, open-circuit oscillator type. The coherer consists of three highly polished tapering steel legs, the lower points of which are

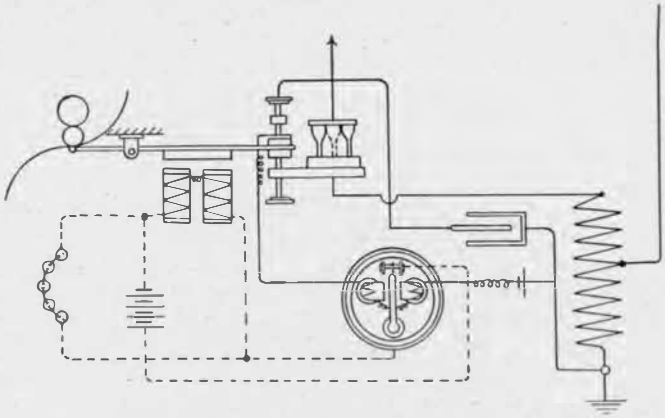
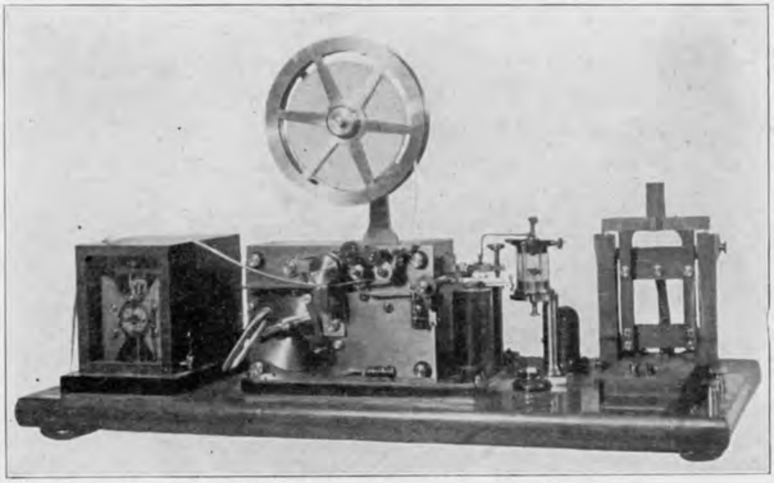


Diagram Branly-Popp System.

Fig. 41.

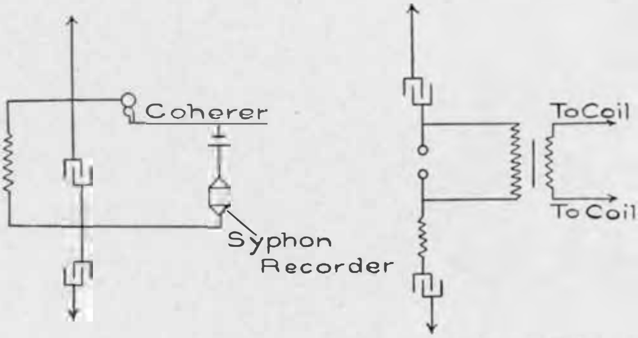
slightly oxidized. The legs are fastened to a metal disc at the top, the points resting on a polished steel plate. In the photograph it will be observed that the coherer is placed immediately back of the



Branly-Popp System.

Fig. 42.

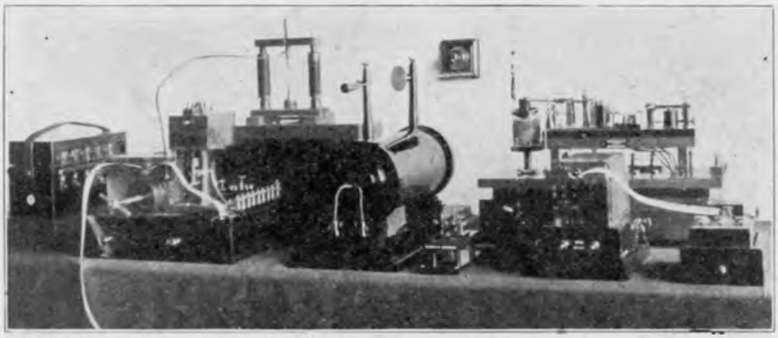
electromagnets of the Morse register, and when the armature is attracted by the magnets, a projecting hammer serves to tap the coherer, restoring the high resistance between the points and making the plate ready for the succeeding impulse.



Lodge-Muirhead System.

Fig. 43.

Lodge-Muirhead. Another recent example of the advances in wireless telegraph practice is the Lodge-Muirhead system, the schematic arrangement being shown in Fig. 43 and the complete apparatus in Fig. 44. The combination of open and closed oscil-



Lodge-Muirhead System.

Fig. 44.

lator and resonator circuits will be recognized as well as the inductance coils and condensers for obtaining resonance effects. The receiver embodies a new rotating mercury coherer, in which a polished steel disc is made to revolve so that its edge runs in, and therefore forms contact with, a column of mercury. Instead of a

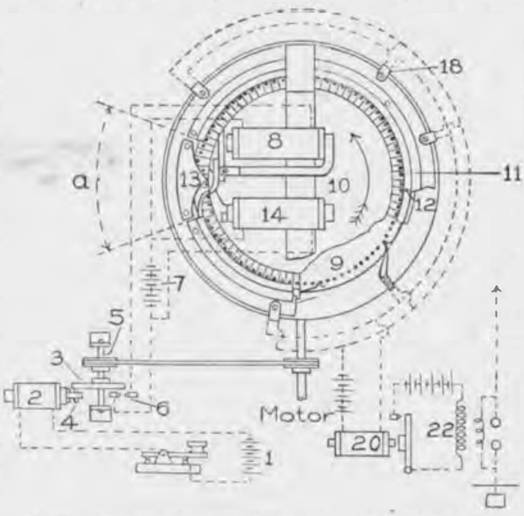
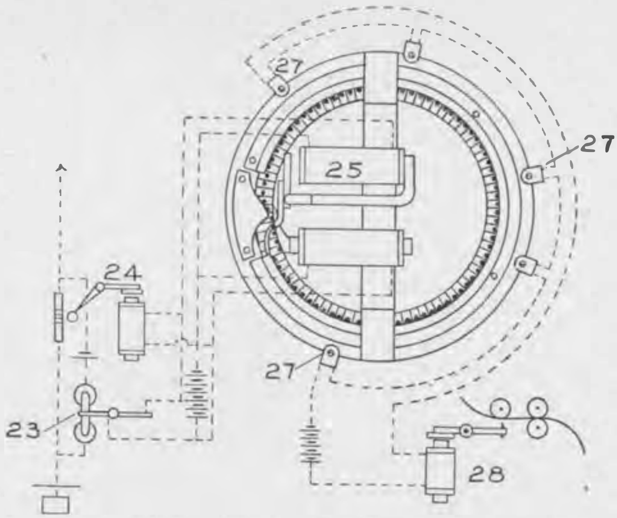


Fig. 45. Transmitter Showing Connections Between Disperser and Induction Coil.

telephone receiver or a Morse register, a syphon recorder such as is used for receiving cable messages is employed and, owing to the comparatively wide variations of resistivity of the coherer, this enables them to be connected direct, thus doing away with the usual relay. The equipment also includes a perforator, for preparing the messages so that they may be sent by an automatic or machine transmitter, although a manually operated key may be used if desired.

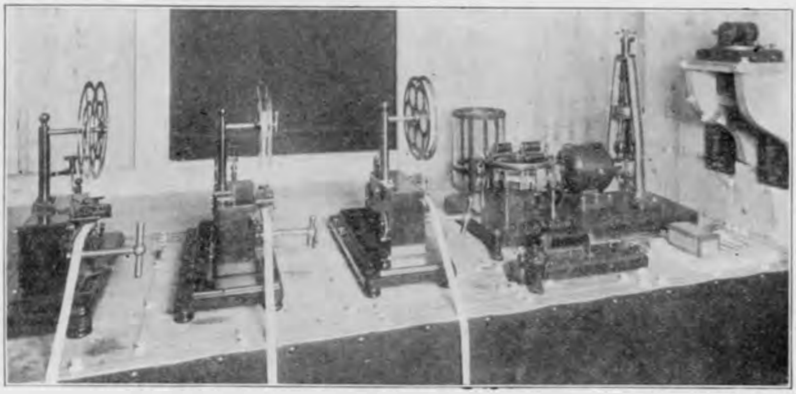
Anders Bull's Electro-Mechanical System. Transmitter.
Fig. 46.

Bull. In all the foregoing systems, where selective signaling was one of the objects to be attained, the desired results were striven for by utilizing the laws of electrical resonance. The solving of the difficult problems of syntonization has, however, been attempted along other and more concrete lines embracing electromechanics of which the following inventions of Anders Bull are the best examples. In this system, the transmitter consists of a *disperser* and an induction coil shown in Figs. 45 and 46; when in operation its function is to send out a fixed number of wave im-



Receiver, Showing Connection Between Coherer Relay, Morse Register, and Collector.
Fig. 47.

pulses per given period of time; these waves actuate different receivers adjusted in accordance with the pre-arranged time intervals. When the key closes the circuit of the battery 1 and the electromagnet 2, the armature of the latter releases a clutch on the disc 3 from the pin 4; the disc is rotated by a frictional shaft 5 making five revolutions per second. Every revolution of the disc causes the pin 6 to close the circuit including the battery 7 and the electromagnet 8; the disperser proper consists of a disc having attached thereto four hundred straight steel springs 9, their free ends passing through a radial slot in the upper revolving disc 10; a brass ring 11 serves as a guide for the spring points and when the disc revolves



Bull's Electro-Mechanical System. Receiver.

Fig. 48.

they slide within a U-shaped groove 12 if attracted by the magnet or within the ring itself when there is no magnetic pull upon them. A bronze arc 13 causes the springs to bend toward the magnet 14, and being energized by the battery, they slide into the groove where they finally close the circuit of the magnet 20 controlling the induction coil 22. As the disc rotates, the springs make contact with projections extending around the frame at certain predetermined intervals and in this way waves of prescribed frequency are consequently emitted.

When these periodically emitted waves impinge upon the antenna of the receiving apparatus, Fig. 47, the coherer closes the circuit of the relay magnets 23; and the tapper 24, and the collector magnet 25 are brought into action. The mechanism of the collector is exactly like that of the disperser and can therefore be instantly converted into a disperser. The discs of the disperser and collector revolve synchronously, hence if five electric wave series are transmitted, five springs will close the circuit at given intervals of time; the spring points 27 of the collector having the same relative arrangement as in the disperser the impulses operate similar contacts controlling the Morse register 28. In this system interference is not obviated, yet any one of a number of receivers in the same field of action may be operated to the exclusion of all others. The Bull receiver is shown in Fig. 48.