WIRELESS TELEPHONY

INSTRUCTION PAPER

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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.

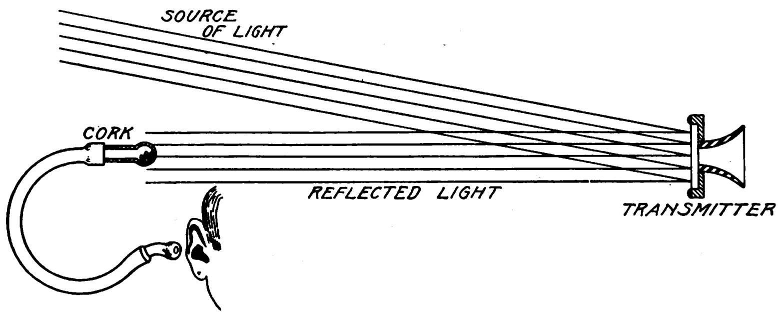

Fig. 1. Bell's Radiophone

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

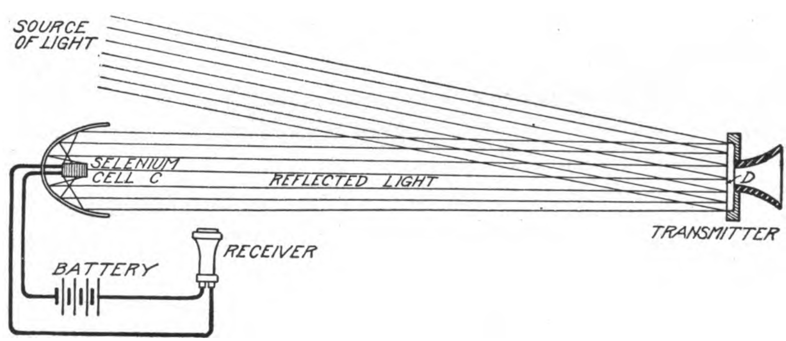

Fig. 2. Bell's Photophone

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

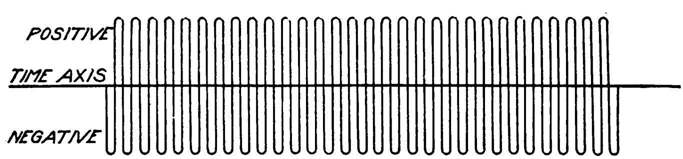

Fig. 3. Diagram Representing High-Frequency Current

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.

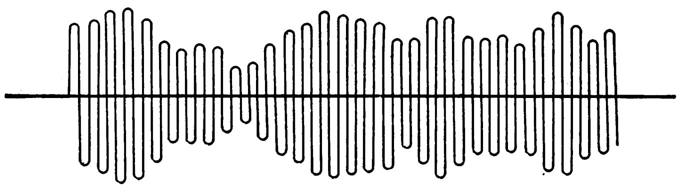

Fig. 4. Diagram Representing Variations of Amplitude

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 radiotelephonic 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.

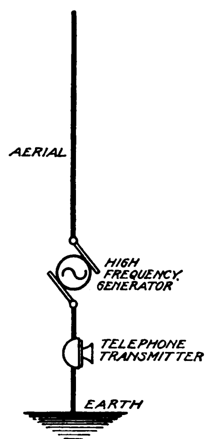

Fig. 6. A Form of Fessenden Circuit

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.

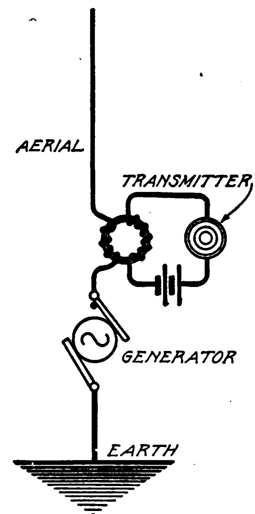

Fig. 7. Transmitter Inductively Associated with Aërial

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

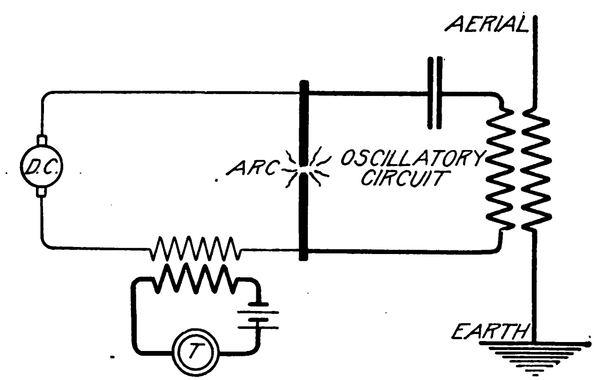

Fig 8. Transmitter Associated with the Supply Circuit

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

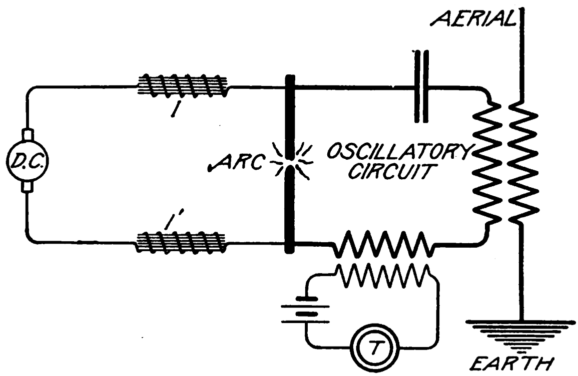

Fig. 9. Transmitter Inductively Associated with the Closed Oscillatory Circuit

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

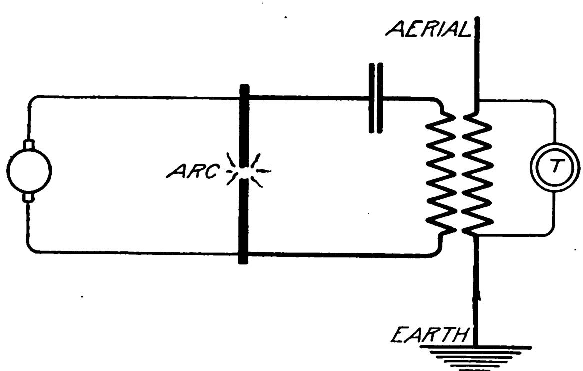

Fig. 10. Transmitter Shunted across the Aërial Inductance

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

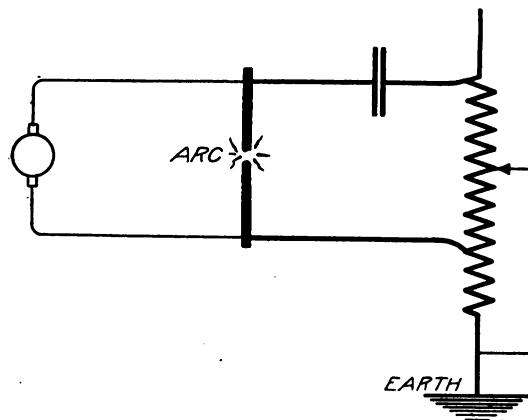

Fig. 11. Transmitter Shunted across a Portion of the Aërial Inductance

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.

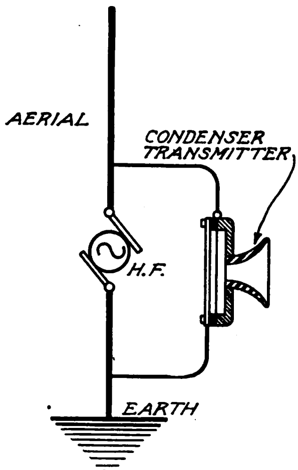

Fig. 12. Condenser Transmitter

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.

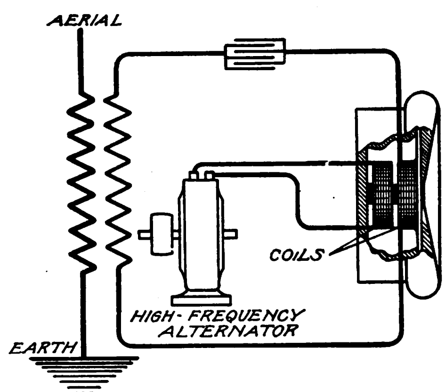

Fig. 13. Heterodyne Receiver Circuit

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 between 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

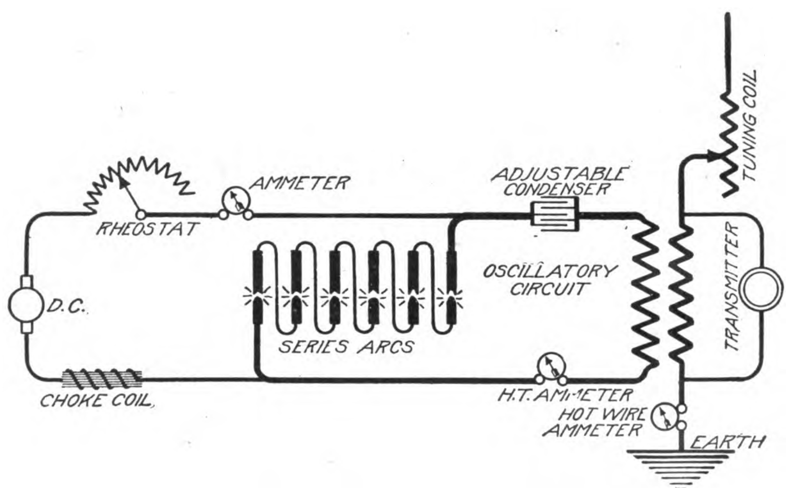

Fig. 14. Transmitter Circuit of the Telefunken System

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.

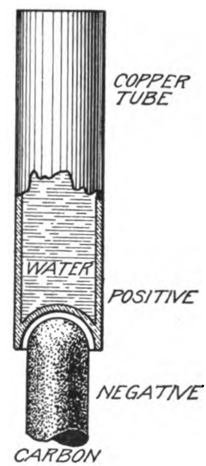

Fig. 15. Telefunken Electrodes

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

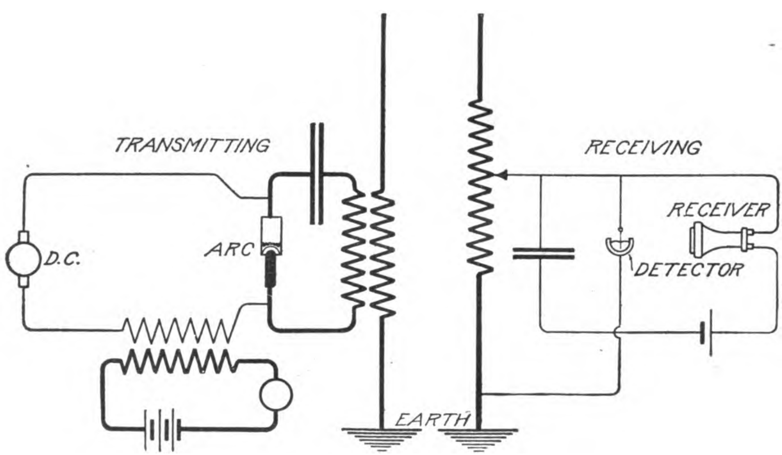

Fig. 16. Circuits of Ruhmer System

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-

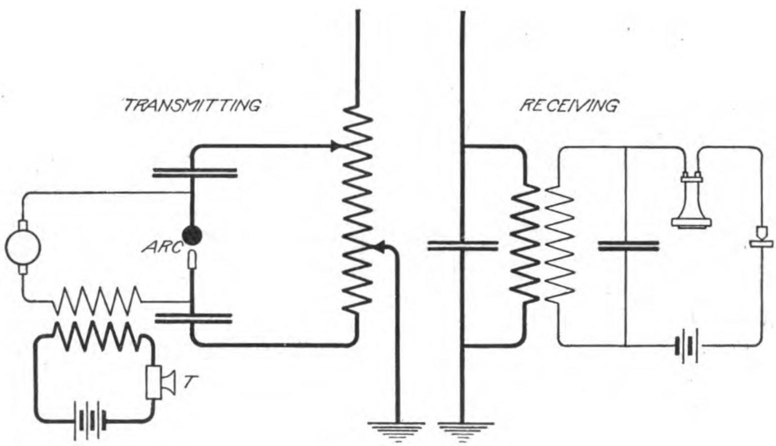

Fig. 17. Circuits of Poulsen System

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 Marjorana 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

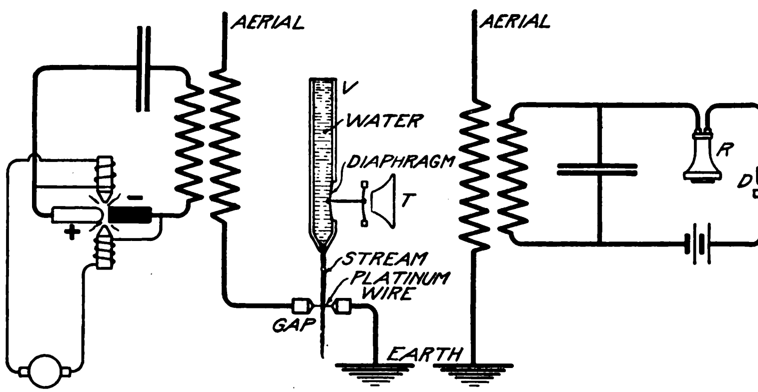

Fig. 18. Circuits of Marjorana System

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-

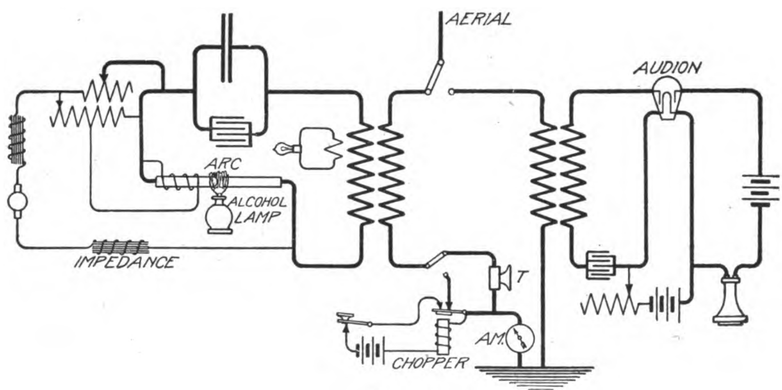

Fig. 19. Operating Circuits of the DeForest System

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

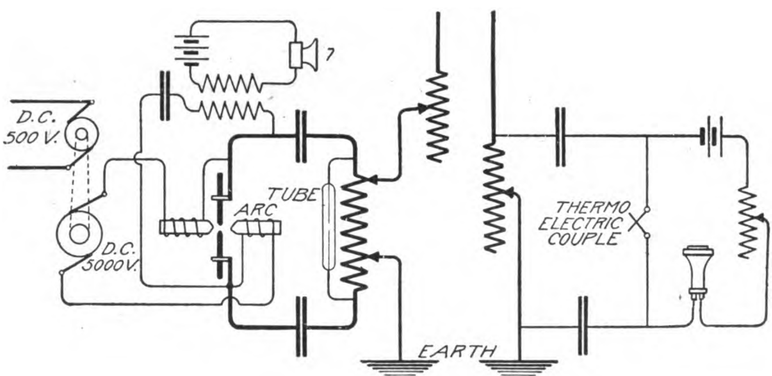

Fig. 20. Circuits of the Collins System

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.

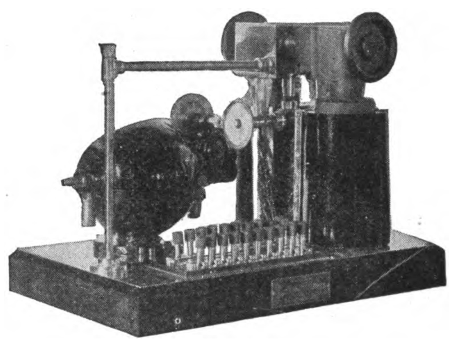

Fig. 21. Collins Revolving Electrodes

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.

WIRELESS TELEPHONY

Read Carefully: Place your name and full address at the head of the paper. Any cheap, light paper like the sample previously sent you may be used. Do not crowd your work, but arrange it neatly and legibly. *Do not copy the answers from the Instruction Paper; use your own words, so that we may be sure that you understand the subject.*

1. What is a Bell radiophone?

2. What is the effect of light on selenium? What is the photophone?

3. Describe the method of causing a direct-current arc to emit musical and other sounds.

4. What is the principal difficulty encountered in applying Hertzian waves to the problem of wireless telephony?

5. Why could not a common telephone transmitter be efficiently used as an interrupter for an induction coil in the production of high-frequency oscillations?

6. What is meant by intermittent wave trains?

7. Describe the method of superimposing a telephone current upon a constantly operating source of oscillations of high intermittency.

8. Name two different methods of creating sustained oscillations.

9. Draw a diagram of the Fessenden method of transmitting radiotelephonically by use of the high-frequency alternator.

10. Name the two most common methods of producing sustained oscillations.

11. Draw three different ways of connecting a telephone carbon transmitter to the oscillatory circuits in order to vary the energy of the radiation therefrom in accordance with the voice current.

12. What detectors may be used for radiotelephony? May a coherer be used?

13. Describe the action of the Fessenden "heterodyne" receiver.

14. Tell why two-way transmission in radiotelephony is not as simple of accomplishment as in ordinary wire telephony.

15. Name seven different radiotelephonic systems.
16. Describe the Telefunken system.
17. Describe briefly the Ruhmer system.
18. Describe the characteristics of the Poulsen system.
19. How does the Marjorana system differ from others?
20. What method of producing sustained oscillations does Fessenden employ?
21. Describe the DeForest system briefly.
22. What detector does DeForest use?
23. Give the general features of the Collins system.
24. Why is the clearness of articulation better in radiotelephony than in wire telephony over long lines and cables?

After completing the work, add and sign the following statement:
I hereby certify that the above work is entirely my own.
(Signed)