WIRELESS TELEPHONY.[1]

[WITH 20 PLATES.]

by R. A. Fessenden[2]

PREFACE.

The discussion of the theory, practical operation, and possibilities of wireless telephony is facilitated by first briefly considering the history of the development of wireless signaling generally.

BRIEF HISTORY OF THE DEVELOPMENT OF WIRELESS SIGNALING.

Introduction. – In preparing this note it has been considered best, for the sake of accuracy, to refer to published results, such as scientific articles or theses or patent specifications. For the sake of brevity, references to work done in repetition of previously published work have as a rule been omitted. So far as possible, the expression of personal opinion has been avoided in this section of the paper, the object being to gather together in concise form the facts known in regard to the development of the art. With the exception of Munk's original paper, which could not be obtained, all references have been verified by consulting the original publications, a work of some labor, and if any omissions or mistakes have been made, data for their correction will be much appreciated.

ORIGIN AND DEVELOPMENT OF OLD OR DAMPED WAVE-COHERER METHOD (PERIOD 1838-1897).

Joseph Henry, to whose work the development of wire telegraphy owes so much, was the first (1838-1842) to produce high frequency electrical oscillations, and to point out and experimentally demonstrate the fact that the discharge of a condenser is under certain conditions oscillatory, or, as he puts it, consists "of a principal discharge in one direction and then several reflex actions backward and forward, each more feeble than the preceding until equilibrium is attained."[3]

This view was also later adopted by Helmholz,[4] but the mathematical

1 Copyright, 1908, by A. I. E. E. Reprinted, by permission, from Proceedings of the American Institute of Electrical Engineers, Vol. XXVII, No. 7, July, 1908, New York.
2 A paper presented at the Twenty-fifth Annual Convention of the American Institute of Electrical Engineers, Atlantic City, N. J., June 29, 1908.
3 Scientific writings of Joseph Henry, Smithsonian Institution.
4 Helmholz, "Erhaltung der Kraft," Berlin, 1847.

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demonstration of the fact was first given by Lord Kelvin in his paper on "Transient electric currents."[5]

In 1870 Von Bezold discovered and experimentally demonstrated the fact that the advancing and reflected oscillations produced in conductors by a condenser discharge gave rise to interference phenomena.[6]

Profs. Elihu Thomson and E. J. Houston in 1876 made a number of experiments and observations on high frequency oscillatory discharges.[7]

In 1883 Professor Fitzgerald suggested at a British Association meeting[8] that electromagnetic waves could be generated by the discharge of a condenser, but the suggestion was not followed up, possibly because no means were known for detecting the waves.

Hertz[9] discovered a method of detecting such waves by means of a minute spark-gap, and before March 30, 1888, had concluded his remarkable series of researches, in which for the first time electromagnetic waves were actually produced by a spark-gap and radiating conductor and received and detected at a distance by a tuned receiving circuit.

Hertz changed the frequency of his radiated waves by altering the inductance or capacity of his radiating conductor or antenna, and reflected and focused the electromagnetic waves, thus demonstrating the correctness of Maxwell's electromagnetic theory of light.

Lodge later in the same year read a paper on the "Protection of buildings from lightning,"[10] before the Society of Arts, in which he described a number of interesting experiments on oscillatory discharges.

Great interest was excited by the experiments of Hertz, primarily on account of their immense scientific importance. It was not long, however, before several eminent scientists perceived that the property possessed by the Hertz waves of passing through fog and material obstacles made them particularly suitable for use for electric signaling.

Prof. Elihu Thomson, in a lecture delivered at Lynn, Mass., on "Alternating Currents and Electric Waves," in 1889, suggested this use.

Sir William Crookes in the Fortnightly Review for February, 1892, discussed the matter in some detail. I quote his statement in full, as it shows what a clear conception he had of the possibilities and obstacles to be overcome:

> Here is unfolded to us a new and astonishing world, one which it is hard to conceive should contain no possibilities of transmitting and receiving intelligence.
>
> Rays of light will not pierce through a wall, nor, as we know only too well, through a London fog. But the electrical vibrations of a yard or more in wave length of which I have spoken will easily pierce such medium, which to them will be transparent. Here, then, is revealed the bewildering possibility of telegraphy without wires, posts, cables, or any of our present costly appliances. Granted a few reasonable postulates, the whole thing comes well within the realms of possible fulfillment. At the present time experimentalists are able to generate electrical waves of any desired wave length from a few feet upward, and to keep up a succession of such waves radiating into space in all directions. It is possible, too, with some of these rays, if not with all, to refract them through suitably shaped bodies acting as lenses, and so direct a sheaf of rays in any given direction; enormous lens-shaped masses of pitch and similar bodies have been used for this purpose. Also an experimentalist at a distance can receive some, if not all, of these rays on a properly constituted instrument, and by concerted signals messages in the Morse code can thus pass from one operator to another. What, therefore, remains to be discovered is: Firstly, simpler and more certain means of generating electrical rays of any desired wave length, from the shortest, say of a few feet in length, which will easily pass through buildings and fogs, to those long waves whose lengths are measured by tens, hundreds, and thousands of miles; secondly, more delicate receivers, which will respond to wave lengths between certain defined limits and be silent to all others; thirdly, means of darting the sheaf of rays in any desired direction, whether by lenses or reflectors, by the help of which the sensitiveness of the receiver (apparently the most difficult of the problems to be solved) would not need to be so delicate as when the rays to be picked up are simply radiating into space in all directions and fading away according to the law of inverse squares.

I assume here that the progress of discovery would give instruments capable of adjustment by turning a screw or altering the length of a wire, so as to become receptive of wave lengths of any preconcerted length. Thus, when adjusted to 50 yards, the transmitter might emit, and the receiver respond to, rays varying between 45 to 55 yards and be silent to all others. Considering that there would be the whole range of waves to choose from, varying from a few feet to several thousand miles, there would be sufficient secrecy, for curiosity the most inveterate would surely recoil from the task of passing in review all the millions of possible wave lengths on the remote chance of ultimately hitting on the particular wave length employed by his friends whose correspondence he wished to tap. By "coding" the message even this remote chance of surreptitious straying could be obviated.

This is no mere dream of a visionary philosopher. All the requisites needed to bring it within the grasp of daily life are well within the possibilities of discovery, and are so reasonable and so clearly in the path of researches which are now being actively prosecuted in every capital of Europe that we may any day expect to hear that they have emerged from the realms of speculation into those of sober fact. Even now, indeed, telegraphing without wires is possible within a restricted radius of a few hundred yards, and some years ago I assisted at experiments where messages were transmitted from one part of a house to another without an intervening wire by almost the identical means here described.

The statement in the last paragraph of the quotation refers to the work of Prof. David E. Hughes.[11]

5 Kelvin, Philosophical Magazine, June, 1853.
6 Von Bezold, Poggendorff's Annalen, 140, p: 541.
7 Journal Franklin Institute, April, 1876.
8 Fitzgerald, "On a method of producing electromagnetic disturbances of comparatively short wave lengths." Report of British Association, 1883.
9 Hertz, "Electric waves."
10 Lodge, Society of Arts, 1888.
11 For report of this work see Electrician, May 5, 1899.

Professor Dolbear also suggested the same thing in an article in Donahoe's Magazine, March, 1893.

In fact, the idea of using Hertzian waves for wireless telegraphy seems to have been quite widespread in the years immediately following Hertz's publications.

Fairly efficient means of generating electromagnetic waves of any desired length had been made known by Hertz. Vertical antenna connected with the ground had been previously used for sending and receiving by Dolbear in 1882 in connection with his system for telegraphing by electrostatic induction[12] and also later by Edison and others.

Hertz's receiver, the minute spark-gap, was not suited for wireless telegraphy, and before any telegraphic work could be done a suitable receiver had to be found.

The fact that tubes containing conducting powders had their resistance altered by the discharge of a Leyden jar and that the original resistance could be restored by tapping the tube was first noted by Munck. in 1835.[13]

In 1890 Branley showed that such a tube would respond to sparks produced at a distance from it.[14]

In 1892, at a meeting of the British Association at Edinburgh, Prof. George Forbes suggested that such a tube would respond to Hertzian waves.

In 1893 Professor Minchen demonstrated experimentally that such powders would respond to electro-magnetic waves generated at a distance.[15] He used a battery and galvanometer shunted around the powder to detect the effect of the waves.

Sir Oliver J. Lodge on June 1, 1894, delivered a lecture before the Royal Institution.[16] In this remarkable lecture Lodge described among other things the following:

1. The filings coherer.
2. The filings coherer in hydrogen under reduced pressure (this in a note added July, 1894).
3. The automatic tapper back for the coherer.
4. The metallic reflector for focusing the waves.
5. The connection of the coherer to a grounded conductor, i. e., a gas-pipe system.
6. The method of making the coherer so connected respond by setting up oscillations in a separate grounded system, i. e., a hot-water pipe system, in another part of the building.
7. The method of detecting distant thunderstorms by connecting the coherer to a grounded gas-pipe system.

12 Dolbear, United States patent No. 350299, March 24, 1882.
13 See Guthe "Coherer action," Transactions of the International Electrical Congress, St. Louis, 1904, p. 242. Munck., Poggendorff Ann., 1838, vol. 43, p. 193.
14 Branley, Comptes Rendus, 1890, p. 785, and 1891, p. 90.
15 Minchen, Proceedings Physical Society, London, 1893, p. 455.
16 Sir O. J. Lodge, "The work of Hertz," Proceedings Royal Institution, June 1, 1904, vol. 14, p. 321.

In this lecture Professor Lodge stated that in his estimate the apparatus used would respond to signals at a distance of half a mile.

Early in 1895 Professor Popoff,[17] of Cronstadt, Russia, constructed a very sensitive filings coherer, one form of which was used in some surveying experiments by the Russian Government,[18] consisting of iron filings suspended by a magnet and resting upon a metallic plate or cup. Other forms consisted of filings in glass tubes with platinum electrodes. He used early in 1895 the automatic tapping back mechanism and substituted for the galvanometer an ordinary telegraphic relay. He operated this apparatus at a distance by means of a large Hertzian radiator. One terminal of his coherer was connected to a conductor fastened to a mast about 30 feet high on the top of the Institute building, and the other terminal of the coherer was grounded.

At the conclusion of his paper, which is dated December, 1895, Popoff made the following statement:

> In conclusion I can express the hope that my apparatus, with further improvements of same, may be adapted to the transmission of signals at a distance by the aid of quick electric vibrations as soon as the source of such vibrations possessing sufficient energy will be found.

Among other experimenters who were working on this subject at the same time may be mentioned Captain Jackson, of the British Navy, and Mr. A. C. Brown.

Marconi, on June 2, 1896, filed a provisional specification[19] showing two forms of apparatus, one similar to Lodge's 1894 apparatus using ungrounded aerials for both sending and receiving and the other for use "when transmitting through the earth or water" substantially identical with Lodge's 1894 and Popoff's 1895 apparatus, with tapper back, etc., and the receiving antenna only being grounded.

Soon after, in July, 1896, Marconi arrived in England and made a number of experiments for the English post-office at Salisbury Plain and elsewhere, using ungrounded aerials and parabolic reflectors and succeeded in reaching nearly 2 miles.

On March 2, 1897, Marconi filed the complete specification in which was included a statement that the transmitting antenna also could be grounded.

Lodge filed a provisional specification[20] showing radiating spheres, but no antenna, on May 10, 1897. The complete specification filed on February 5, 1898, shows as one form both antenna grounded and also the use of an inductance wound in the form of a coil for the purpose of diminishing the rate of damping of the waves.

So far as is known little work was done in America during this period.

17 Journal Russian Physico-Chemical Society, vol. 27, April 25, 1895.
18 A. S. Popoff, "Apparatus for detection and registration of electrical vibrations," Journal Russian Physico-Chemical Society, vol. 28, December, 1895.
19 Marconi, Great Britain patent No. 12039, 1896.
20 Lodge, Great Britain patent No. 11575, 1897.

The writer made some experiments in 1896 and in conjunction with two of his students, Messrs. Bennett and Bradshaw, did considerable work on receivers of various types in the fall of 1896 and spring of 1897, the results of which were incorporated in a thesis.[21]

Return to First Principles and Foundation, on Lines Antithetical to Old, of New or Sustained Oscillation Nonmicrophonic Receiver Method (1898).

Up to the year 1898, as may be seen from the above, the development of wireless telegraphy had proceeded along a single line. In that year, however, an entirely new method of wireless telegraphy was developed, characterized by a return to first principles, the abandonment of the previously used methods and by the introduction of methods in almost every respect their exact antitheses.

While the coherer is of more or less interest theoretically it is not adapted for use for telegraphic purposes. Responding as it does to voltage rises above a certain limit, it does not discriminate between impulses of different characters, and is therefore peculiarly susceptible to interfering signals and atmospheric disturbances, and the operation of coherer systems can not be guaranteed during the summer months or in the Tropics. Roughly speaking, a coherer acts by starting an arc and making a short circuit on the line every time a signal is received, which short circuit persists until it is broken by a blow from an additional mechanism, and such a method of operation is obviously far from practical. In addition, it is practically impossible to obtain sharp tuning in a local circuit containing a coherer; its action is always more or less erratic, its electrostatic capacity variable, and it is insensitive.

At the sending end the energy which can be liberated by the discharge of an antenna is limited, and in the form used prior to 1897 the dampening is so great that there are only a few oscillations per spark.

Lodge,[22] by placing a coil of large inductance in the antenna, throttled down the amount of energy radiated per oscillation and so obtained with the same limited amount of energy derived from the charged antenna, an increase in the time of damping.

Braun[23] patented the method of using a local oscillatory circuit connected to an antenna, the local oscillatory circuit having a much longer period than the natural period of the antenna and of a different order of magnitude. Such a system, however, does not radiate energy appreciably, and produces a damped wave.

This dampening and the limited amount of energy obtainable by charging and discharging the antenna operates to prevent sharp tuning and working over long distances.

21 Western University of Pennsylvania, May, 1897.
22 Lodge, Great Britain patent No. 11575, 1897.
23 Braun, German patent No. 11578, October 14, 1898.
24 Electrical World, July 29, August 12, September 16, 1899, and Proceedings American Institute of Electrical Engineers, November, 1899, page 635, and November 20, 1906, page 781.

The coherer is well adapted for working with damped waves, but the coherer-damped wave method can never be developed into a practical telegraph system. It is a question whether the invention of the coherer has not been on the whole a misfortune as tending to lead the development of the art astray into impracticable and futile lines and thereby retarding the development of a really practical system.

The fact that no coherer-damped wave system could ever be developed into a practically operative telegraph system, and the fact that it was necessary to return to first principles and initiate a new line of development along engineering rather than laboratory lines was perceived in America in 1898[24] and a new method was advised which may be called the sustained oscillation-nonmicrophonic receiver method as opposed to the damped oscillation-coherer method previously used.

Fundamental Differences Between the Old and New Wireless Schools.

The differences between the two methods are shown in tabulated form:

	Damped oscillation-coherer method.	Sustained oscillation-nonmicrophonic method.
A 1	Damped oscillations are produced at the sending end.	Sustained oscillations are produced at the sending end.
A 2	The energy transmitted is obtained by charging the antenna and discharging it.	The energy transmitted is derived from a local source and fed into the antenna.
A 3	A spark gap is used for producing the oscillations.	An arc or high frequency dynamo is generally used for producing the oscillations.
B 1	Imperfect or microphonic contact receivers are used.	Nonmicrophonic contact receivers are used.
B 2	The action of the receiver depends upon the voltage rise and is independent of the amount of energy received.	The receiver response is determined by the integral amount of energy received.
B 3	An open-tuned circuit is used for receiving.	A closed tuned circuit is used for receiving.
B 4	The receiving circuit is tuned to the wave frequency only.	The receiving circuit may be tuned to a group frequency as well as to the wave frequency.
C 1	In transmitting messages the production of the electromagnetic waves is intermittent.	The waves are preferably generated continuously and the transmission accomplished by changing the character of the wave.
C 2	The wave energy flux is intermittent	The wave energy flux is constant.
C 3	A high voltage is used	A low voltage is used.
C 4	Comparatively short wave lengths are used.	Comparatively long wave lengths are used.
C 5	The signals consist of dots and dashes, whose interpretation is fixed.	The signals may consist of dots only, whose interpretation depends on the station sending and receiving.
D 1	Antennæ are used adapted, roughly speaking, to utilize the electrostatic component of the electromagnetic waves.	The antennæ are preferably arranged so as to utilize the other component of the electromagnetic waves instead of the electrostatic component.

The history of these two antithetical lines of development will be treated of separately.

Development and Perfecting of Sustained Oscillation-non-microphonic Receiver Method (Period 1898-1902).

The Current-Operated Receiver.

The first essential for the development of the system was, of course, a quantitatively responsive receiver. Several forms of this were tried, including the modification of the Boys' radio-micrometer (consisting of a light thermo couple suspended in the field of a permanent magnet and heated by radiation from a wire, which in turn was heated by the current to be detected) described by the writer at the Columbus meeting of the American association in 1897.[25] This was abandoned in favor of Prof. Elihu Thomson's alternating current galvanometer,[26] suitably modified for telegraphic work.[27]

Among other forms of current-operated receiver may be mentioned the following:

The hot-wire barretter,[28] consisting of a minute platinum wire a few hundred thousandths of an inch in diameter and approximately a hundredth of an inch in length. The term "barretter" was coined for this device for the reason that it differs essentially from the bolometer of Langley in that it is arranged to be affected by external sources of radiant heat as little as possible instead of as much as possible, and to have an extremely small specific heat, an object not sought in the case of the bolometer.

The liquid barretter,[29] in which the change of resistance is effected by heating a liquid, the concentration of path being obtained by means of a fine platinum wire point. Some question has been raised as to the theory of operation of this device, but I think there is no question but that the effect is due to heat, though what per cent of the effect is due to change in ohmic conductivity by heat and what per cent is due to depolarization by heat is still, as originally stated by the writer,[29] uncertain. The facts that the device operates practically equally well irrespective of which terminal is connected to the local battery, and that the effect varies as the square of the alternating current (as a heat-operated device should do) instead of directly with the alternating current as a rectifier would do, and that depolarization is produced by the heat, have been confirmed by Dr. L. W. Austin.[30] The writer has experimentally determined the fact that though the electrical impulses may have a duration of less than a millionth part of a second, the change in resistance persists for approximately the ten thousandth part of a second, which would seem

25 Electrician, June 24, 1904.
26 Elihu Thomson, United States patent No. 363185, January 26, 1887.
27 United States patents Nos. 706736 and 706737, December 15, 1899.
28 United States patent No. 706744, June 6, 1902.
29 United States patent No. 727331, April 9, 1903.
30 Austin, Bulletin of the Bureau of Standards, vol. 2, No. 2.

to show conclusively that the action is not a direct effect of the waves.

The term electrolytic receiver has sometimes been applied to the liquid barretter. This is objectionable, as there are a number of electrolytic receivers. For example, the Neughschwender-Schaefer[31] receiver, in which a number of microscopic filaments are produced between two terminals by electrolysis, which filaments are ruptured by the wave-produced oscillations, thus increasing the resistance; also the liquid coherer of Captain Ferrie, described by him as follows:[32]

> The same effect of self-decohering coherence has been determined for a contact of a metallic wire and a liquid conductor, acidulated water, contained in a glass tube of small diameter, and placed under the same conditions as the preceding. Always, the sensitiveness of this contact is very notably inferior to that obtained in the experiments disclosed above. The maximum sensitiveness was obtained when the resistance of the imperfect contact was about 2,000 ohms and when the extremity of the metal wire scarcely grazed the meniscus of the liquid. The results obtained were better with a copper wire, attacked by the acidulated water, than with a platinum wire.

This coherer probably acts through a chemical effect producing a thin film of gas and has never come into use, doubtless because, as Captain Ferrie points out, it is even less sensitive than the Marconi coherer. Also the rectifier of Pupin,[33] in which the terminals are placed so closely together that practically no energy is absorbed in the receiver, in order that the rectified energy may be utilized outside in the external circuit, in opposition to the liquid barretter, where the position of the terminals is such that all the received wave energy is absorbed in the barretter for the purpose of producing a secondary effect, and so influencing the current in a shunted local circuit.

Methods of Obtaining Sustained Oscillations.

Spark-gap, and local oscillatory or "tank" circuit. – Prof. Elihu Thomson discovered that by using a transformer without an iron core (the well-known Elihu Thomson air-core transformer, later used by Tesla and others) and a spark-gap and condenser in the primary circuit, and with the secondary circuit suitably tuned great resonant rises of potential could be obtained. In 1892 he constructed such a transformer giving discharges 64 inches long.[34]

The same method was later used by Tesla[35] his experimental researches and in his attempt to carry out Loomis's[36] method of transmitting a current through a hypothetical conducting stratum in the upper regions of the atmosphere.

The device, suitably modified for wireless telegraphic purposes,

31 Neughschwender, German patent No. 107843, December 13, 1898, and Schaefer, British patent No. 6002, 1899.
32 Blondel, L'Ecairage Electrique, September 29, 1900.
33 Pupin, United States patent No. 713044, January 4, 1898.
34 Electrical World, February 20 and 27, 1892.
35 United States patent No. 645516, September 2, 1897.
36 Loomis, United States patent No. 129971, July 30, 1872.

so as to give, instead of a continuously cumulative rise of potential, an initial rise of potential followed by a gradual feeding in of the energy from the local circuit to supply the energy lost from radiation, was made use of in 1898 for the purpose of producing prolonged trains of sustained waves.

Various types of connection between the antenna and the local oscillatory circuit were tested, but it was found that the most efficient results were obtained by connecting the local circuit directly across the sparkgap.[37]

The results of some comparative tests are here given. The figures in the column "A" are for the local circuit connected directly to the terminals of the spark-gap, those in column "B" are for an autotransformer, those in column "C" for a loose-coupled primary and secondary.

	A.	B.	C.
Frequency	212,000	212,000	212,000
Tank capacity (m. f.)	0.072	0.072	0.072
Kilowatt output dynamo	30	30	30
Tank current (amperes)	400	370	300
Antenna current	48.5	46	48

The large station at Brant Rock is operated with the local circuit directly connected across the spark-gap, partly because the efficiency is somewhat greater, but also on account of the great simplification of connections and the fact that the degree of sustainment of the wave train may be adjusted very simply, if desired, by sliding the lower terminal of the antenna along a few inches of the lead of the local oscillatory circuit.

Cooper-Hewitt[38] in 1902 used a modification of his mercury lamp to obtain intermittent discharges, each followed by a train of high-frequency oscillations.

Arc methods. – The worker with high-frequency oscillatory currents will soon discover that we are indebted to the genius of Prof. Elihu Thomson for practically every device of any importance in this art.

The method of producing high frequency oscillations from an arc and continuous current was discovered by him in 1892.[39] Figure 1, taken from his patent, shows the general form of his arrangement. If the directions given in the specification are followed no difficulty will be met with in obtaining frequencies as high as 50,000 per second.

Between 1900 and 1902 some experiments were carried out with the Elihu Thomson are as a source of high frequency oscillations for wireless telegraphy and telephony.

Some difficulties were found, for example, the arc could not be started and stopped as quickly as was necessary for telegraphic purposes, and the intensity of the oscillations and their frequency varied considerably.

37 United States patents Nos. 706735 and 706736, December 15, 1899.
38 Cooper-Hewitt, United States patent No. 780999, April 25, 1902.
39 Elihu Thomson, United States patent No. 500630, July 18, 1892.

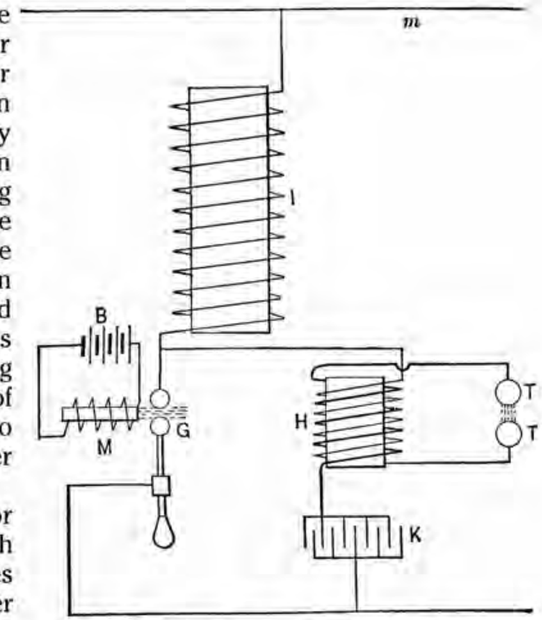


FIG. 1.—Elihu Thomson's method of producing high frequency oscillations.

These were overcome by making some minor improvements, for example, the difficulty in sending was overcome by permitting the arc to run continuously and using the key to change the electrical constants of the circuits.[40] The difficulty in keeping the intensity and frequency constant was overcome by substituting resistance for a portion of the inductance, and also by using the arc under pressure.[41]

Tests made by Doctor Austin[42] show that with this method frequencies as high as 3,000,000 per second and efficiencies as high as 60 per cent can be obtained together with an absolutely steady[43] generation of the high frequency currents and an absence of harmonic frequencies.

High frequency alternator. – The first, high frequency alternator was built by Prof. Elihu Thomson in 1889. And it[44] was while experimenting with it in 1900 that Doctor Tatum made his very interesting discovery that high frequency currents of large amperage could be passed through the body without injury.[45]

From 1898 to 1900 numerous experiments were made on antenna of large capacity, and it was found that instead of using sheets of solid metal or wire netting, single wires could be placed at a considerable fraction of the wave-length apart and yet give practically the same capacity effect as if the space between them were filled with solid conductors.

From other investigations on the variation of radiation with frequency

40 United States patents Nos. 706742, July 6, 1902; 706747, September 28, 1901; 727330, March 21, 1903; 730753, April. 9, 1903.
41 Ibid and United States patent No. 706741.
42 Austin, Bulletin of the Bureau of Standards, vol. 3, No. 2.
43 Austin assumed from the figure he obtained for the dampening, that the oscillations were not continuous; but the method used for determining the dampening is not applicable to this case, and a comparison of the currents and voltages with the frequencies given in Austin's experiments, shows that these oscillations must have been continuous.
44 Thomson, Electrical Engineer, July 30, 1890, and London Electrician, September 12, 1890.
45 Thomson, Electrical Engineer, March 11, 1891.

the result was arrived at that it should be possible to construct an alternating-current dynamo of sufficiently high frequency and output to give ample radiation for wireless telegraphic purposes.[46]

In 1900 a large American electrical manufacturing company kindly consented to take up the construction of such a dynamo. As a preliminary, a dynamo of 1 kilowatt output and 10,000 cycles (shown in pl. 1, fig. 1) was built in 1902. By the summer of 1906 many of the difficulties had been overcome, and a machine giving 50,000 cycles was installed at the Brant Rock station. Various improvements were made by the writer's assistants, and in the fall of 1906 the dynamo was working regularly at 75,000 cycles, with an output of half a kilowatt, and was being used for telephoning to Plymouth, a distance of approximately 11 miles. In the following year machines were constructed having a frequency of 100,000 cycles per second and outputs of 1 and 2 kilowatts.

The credit for the development of this machine is due to Messrs. Steinmetz, Haskins, Alexanderson, Dempster, and Geisenhoner, and also to the writer's assistants, Messrs. Stein and Mansbendel.

Closed Tuned Circuits.

In 1898 the open tuned circuits originally used were discarded for closed tuned circuits,[47] and it was discovered that valuable selective effects could be obtained by placing the condenser in shunt to the inductance, instead of in series with it.[47]

Plate 1 Fig. 1 – Preliminary Dynao, 1 Kilowatt, 10,000 Cycles.

Combination of Wave and Group Tuning.

The fact that if selectivity is obtained solely by tuning to wave frequencies, the number of stations is limited, was appreciated at an early date. In 1900[48] a new method was developed, the stations being tuned both to the wave frequency and to an independent or group frequency, so that stations might obtain selectivity by varying either the wave or the group frequency and thus have at their disposal a virtually unlimited number of combinations and be practically free from atmospheric disturbances. Plate 1, fig. 2, shows a type of group tuner.

Further Development of Damped Wave-coherer Method.

Marconi, by 1898, had carried the development of the filings coherer to its maximum point.

46 United States patent No. 706737, May 29, 1901.
47 United States patents Nos. 706735 and 706736, December 15, 1899.
48 United States patents Nos. 727325, June 2, 1900, and 727330, March 21, 1903.

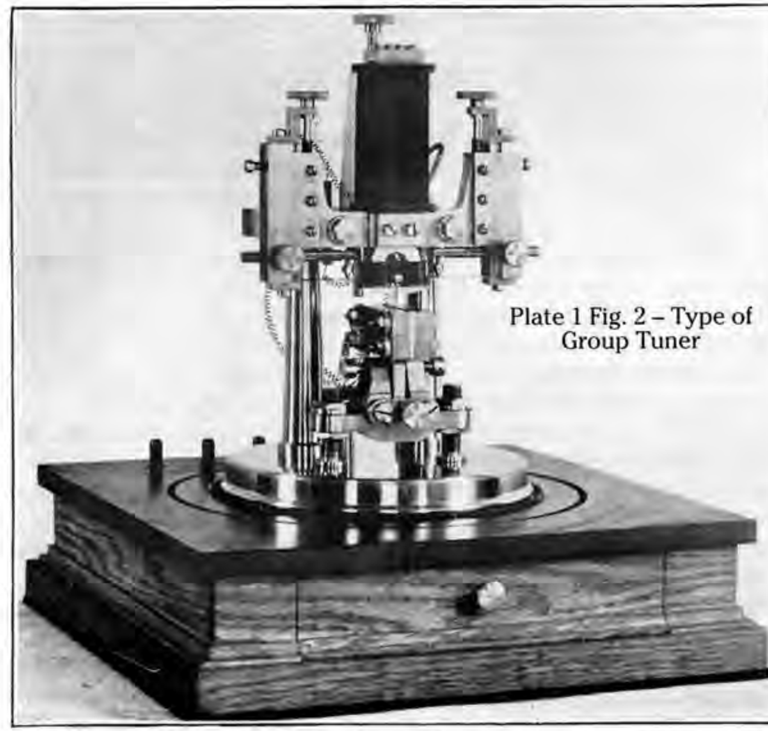


Plate 1 Fig. 2 – Type of Group Tuner

Lodge in 1897[49] had disclosed the open secondary circuit for receiving.

Marconi in 1898[50], greatly improved this by adjusting the length of the secondary so as to tune it, and by the aid of this improvement was enabled to telegraph a distance of 35 miles[51] in October, 1899.

Lodge in 1902[52] invented what is perhaps the most perfect form of coherer, consisting of a thin steel disk dipping in oil-covered mercury and automatically decohered by being kept in continuous rotation.

A number of self-restoring coherers, of which the Brown[53] carbon coherer may be taken as a type, including the mercury carbon coherer of Solari, came into more or less extended use, and also modifications of the imperfect contact receiver of Neugschwender.[54]

The small progress made along these lines is to be explained by the fact that the damped wave-coherer system is essentially and

49 Lodge, Great Britain patent No. 11575, May 10, 1897.
50 Marconi, Great Britain patent No. 12326, June 1, 1898.
51 Official report United States Navy of test U. S. S. Massachusetts, October, 1899.
52 Lodge, Muirhead & Robinson, Great Britain patent No. 13521, June 14, 1902.
53 Brown & Neilson, Great Britain patent No. 28955, December 17, 1896.
54 A. Neugschwender, Wied. Ann. der Physik, 1899, vol. 67, p. 430. Schaefer, British patent No. 6002, 1899.

fundamentally incapable of development into a practical system.

Later Developments (Period 1902-1908).

Progress in Europe since 1902 has been marked by the gradual abandonment of the elements of the damped wave-coherer system and the substitution of elements of the sustained wave nonmicrophonic contact type.

In 1900[55] Marconi substituted for the plain aerial an aerial with the writer's tuned local circuit or tank circuit for sending, thus obtaining a considerable increase in range of transmission.

In 1902 Marconi invented a very ingenious form of current-operated receiver, called the magnetic detector,[56] and with this combination achieved some very remarkable results.

In 1905 Professor Fleming[57] invented a very efficient detector based on the "Edison effect" in incandescent lamps, and the observations of Elster and Geitel[58] on the rectifying effect of such an arrangement on Hertzian oscillations.

Virtually nothing was done in Europe in the way of producing sustained oscillations by the arc or high frequency method until recently, possibly because of Duddell's erroneous statement[59] to the effect that frequencies much above 10,000 could not be obtained by the Elihu Thomson arc method, and Fleming's statement[60] that an abrupt impulse was necessary and that high frequency currents, even if of sufficient frequency, could not produce radiation.

In 1903 Poulsen[61] invented an interesting modification of the Elihu Thomson arc, which consists in forming the arc in hydrogen instead of in air or compressed gas as previously done. This modification is not, however, so efficient as the older methods and gives oscillations varying in amplitude and intensity and accompanied by strong harmonics,[62] but I have considered it worth mentioning on account of the amount of interest it appears to have excited in Europe.

Some very important and interesting papers on electrical oscillations were published during, these years by Oberbeck,[63] Wien,[64] Drude,[65] and Bjerknes.[66]

In America the development of the sustained oscillation nonmicrophonic system has proceeded steadily and it may now be said

55 Marconi, Great Britain patent No. 7777, April 26, 1900.
56 Marconi, Great Britain patent No. 10245, 1902.
57 Fleming, Proceedings Royal Society London, 1905, vol. 74.
58 Elster and Geitel, Wied. Ann. de Physik, vol. 52, P. 433.
59 Duddell, The Electrician, 1903, vol. LI, p. 902.
60 Fleming, Proceedings of the International Congress, St. Louis, 1904, vol. 3, p. 603.
61 Poulsen, United States patent No. 789449, June 19, 1903.
62 Austin, Bulletin of the Bureau of Standards, vol. 3, No. 2.
63 Oberbeck, Wied. Ann. der Physik, vol. 55, 1895.
64 Wied. Ann. der Physik, vol. 8, 1902.
65 Drude, Ann. der Physik, vol. 13, 1904.
66 Bjerknes, Ann. der Physik, vol. 44, 1891, and vol. 47, 1892.

to have reached the stage of commercial practicability. On account of the amount of work which has been done it is impossible to refer to more than a few of the recent advances.

The following are some of the later types of detectors:

The frictional receiver[67] in which the waves produce a change of friction between two moving surfaces and so cause an indication.

The heterodyne receiver,[68] in which a local field of force actuated by a continuous source of high-frequency oscillations interacts with a field produced by the received oscillations and creates beats of an audible frequency.

The so-called "thermoelectric receivers" of Austin,[69] Pickard,[70] and Dunwoody.[71]

The "audion" of De Forest,[72] a very interesting and sensitive device, which though superficially resembling Professor Fleming's rectifier appears to act on an entirely different principle.

The Cooper-Hewitt mercury receiver, about which little is known, but which appears to be very sensitive.

The following are some of the later methods of producing sustained oscillations:

The substitution of a number of arcs in series having terminals of large heat capacity in place of the single are in the are method.[73]

The use of regulating or "fly-wheel" circuits in connection with the are method.[73]

The method of producing oscillations shown in plate 2, figure 1, by using two arcs and throwing the discharge from one side to the other alternately at a frequency regulated by the constants of the electric circuit.[73]

The condenser dynamo[74] which consists of two radially slotted disks separated by a mica diaphragm, charged by a continuous current source of potential, and rotating in opposite directions.

Two-phase high-frequency dynamo method.[75]

Commutator method.[76] In this method the high frequency is produced by means of a ball rotating at high speed on the interior surface of a commutator (pl. 2, fig. 2).

The helium are method,[77] in which the arc is produced in helium or argon or similar gases.

The critical pressure method,[78] in which the electrodes extend within a certain critical distance, depending upon the pressure used,

67 United States application No. 251538, March 22, 1905.
68 United States application No. 271539, June 28, 1905.
69 Austin, United States application No. 319241, May 29, 1906.
70 Pickard, United States application No. 342465, November 8, 1906.
71 Dunwoody, United States patent No. 837616, March 23, 1906.
72 De Forest, United States patent No. 836070, January 18, 1906.
73 United States application No. 291737, December 14, 1905.
74 United States application No. 291739, December 14, 1905.
75 United States patent No. 793649, March 30, 1905.
76 United States application No. 316521, May 12, 1906.
77 United States application No. 351560, January 7, 1907.
78 United States application No. 355787, February 4, 1907.

so that the discharge always passes at the same voltage irrespective of the distance between the electrodes.

Methods of signaling. – Continuous production of waves but changing constants of sending circuit.[79]

The inverted method of sending and the method of signaling by sending dots, the interpretation of which is determined by similar commutators at the sending and receiving stations.

Duplex and multiplex methods. – A considerable number of these have been worked out, mostly operating either by balance methods,[80] or commutators.[81] It is impossible to discuss all the various improvements, such, for example, as the method of indicating the busy and free state of a station, the methods of sending and receiving in one direction, the various types of aerials used for receiving the other components of the electromagnetic waves besides the electrostatic component, etc.

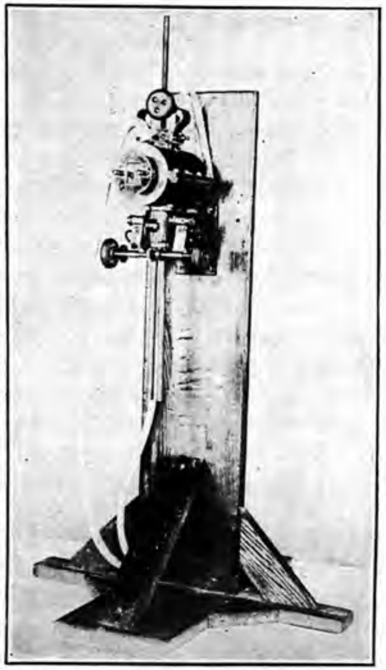


Plate 2 Fig. 1 – Apparatus for Producing Oscillations.

Plate 3, figure 1, shows the harmonic interrupter for determining the variation of intensity with change of note.

Plate 3, figure 2, shows a type of receiver described in United States patent No. 706747, in which the

Plate 2 Fig. 2 – Commutator Method of Producing Oscillations

79 United States patents Nos. 706747, September 28, 1901; 706742, June 6, 1902; 727747, March 21, 1903.
80 United States application No. 366528, April 5, 1907.
81 United States patent No. 793652, April 6, 1905.

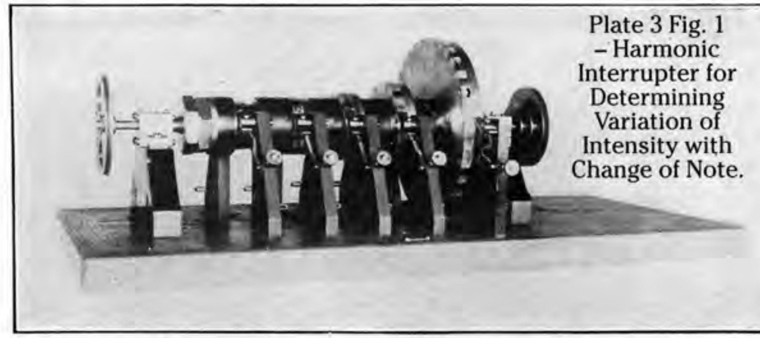


Plate 3 Fig. 1 – Harmonic Interrupter for Determining Variation of Intensity with Change of Note.

telephone diaphragm is formed of thin copper and repelled by a fixed coil having a resistance of about 16 ohms. The principle of this receiver was discovered by Prof. Elihu Thomson. It has been used for wireless telephony for a distance of 11 miles with fairly satisfactory results.

Plate 3 Fig. 2 – Wireless Telephone Receiver, with Thin Copper Diaphragm Repelled by Resistance Coil of 16 Ohms.

Plate 3, figure 3, shows a transformer used in the transmitting circuit. The number of primary and secondary turns can be altered continuously, and also the degree of coupling. The wire is wound off from an insulating cylinder onto a cylinder of copper, and the cylinder of copper, forming a closed circuit secondary of the transformer, annuls the

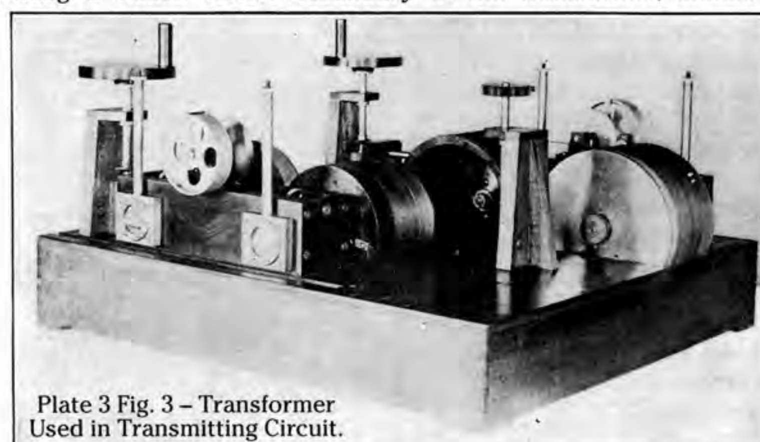


Plate 3 Fig. 3 – Transformer Used in Transmitting Circuit.

inductance of that portion of the wire wound upon the copper cylinder.

Plate 4 shows a group-tuned call; that is, a vibration galvanometer which operates a selenium cell and rings a bell when a call is received.

Plate 5, figure 1, shows an apparatus for determining the best shape of coil for use with the heterodyne receiver.

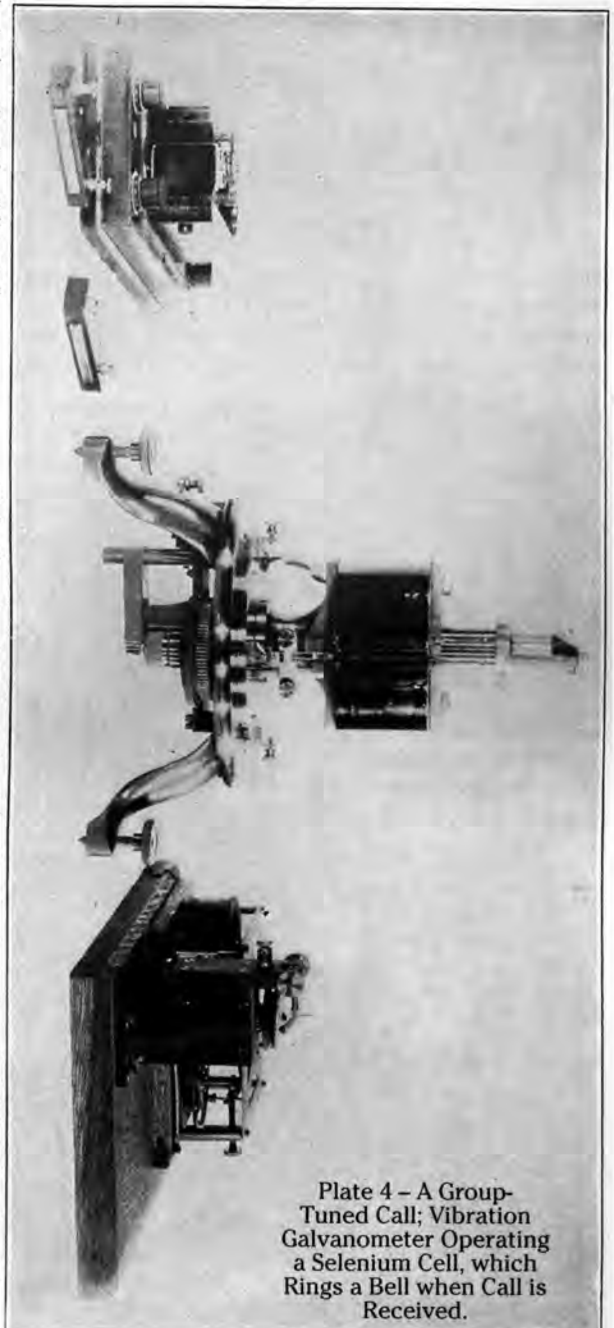


Plate 4 – A Group-Tuned Call; Vibration Galvanometer Operating a Selenium Cell, which Rings a Bell when Call is Received.

THEORY OF WIRELESS TELEPHONY.

For wireless telephony three things are necessary:

1. Means for radiating a stream of electrical waves sufficiently continuous to transmit the upper harmonics on which the quality of the talking depends.
2. Means for modulating this stream of waves in accordance with the sound waves.
3. A continuously responsive receiver, giving indications proportional to the energy received and capable of responding with sufficient rapidity to the speech harmonics.

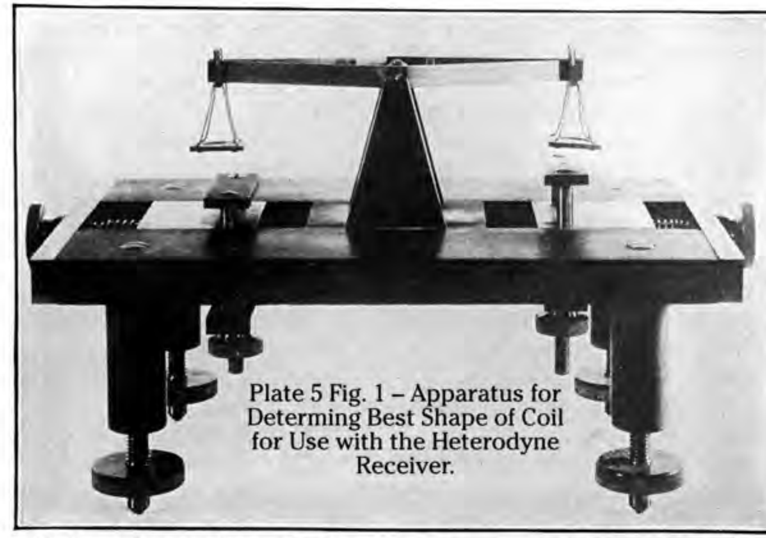


Plate 5 Fig. 1 – Apparatus for Determing Best Shape of Coil for Use with the Heterodyne Receiver.

Work on the wireless telephone was commenced before a satisfactory means was discovered for producing sustained oscillations.

To ascertain the number of sparks per second which was necessary to determine articulate speech, a phonograph cylinder was taken and grooves were cut in it longitudinally. It was found in this way that practical transmission could be accomplished with 10,000 breaks per second. It is believed now that this number is unnecessarily high, possibly owing to the fact that it was impossible to cut the grooves on the cylinder without producing ridges. The lower limit may be fixed in another way.

Electrical circuits met with in actual working have resistance, self-inductance capacity, and leakance. Heaviside gave the differential equations for the pressure and current over such circuits when alternating voltages were applied, but no method of solution being known, the mathematical treatment of such circuits was restricted to cases where one of the constants was neglected, until Dr. A. E. Kennelly in a masterly series of papers gave the complete solution.

The results were immediately found applicable to a great variety of problems, such as the transmission of signals through cables and of telephonic speech through various types of circuits.

In this way Doctor Kennelly[82] by comparing the results obtained by Dr. Hammond V. Hayes[83] in practical telephonic transmission over loaded lines with the theoretical values of the current for different harmonics showed that harmonics above 2,000 per second could be neglected for telephonic transmission.

The writer has never succeeded in obtaining good talking with such a low frequency, but under favorable conditions fairly satisfactory speech

82 Kennelly, "Distribution of pressure and current over alternating-current circuits," Harvard Engineering Journal, 1906, p. 43.
83 Hayes, "Loaded telephone lines in practice," Transactions International Electrical Congress, St. Louis, vol. 3.

may be obtained with 5,000 interruptions per second. For really good transmission, however, the radiation must be practically continuous, for if the spark frequency is less than 20,000 per second there is a disagreeable high pitch note in the telephone, not noticeable perhaps at first but apt to become annoying with use. The most satisfactory way is, of course, to use a source of sustained oscillations.

It fortunately happens that for wireless telephonic purposes it is inadvisable to use a wave frequency of less than 25,000 per second, on account of the difficulty in radiating energy with low frequencies.

The receiver must, of course, be continuously responsive. If, for example, it had to be tapped back in order to restore it to the responsive condition, speech could not be transmitted.

It must also give indications proportional to the energy received or the character of the speech will be distorted.

It must also respond with sufficient rapidity. If, for example, it takes a thousandth of a second to restore itself to its original resistance the receiver will obviously not record the higher harmonics. I have experimentally determined that a receiver which restores itself in the ten thousandth part of a second acts with sufficient rapidity.

History of the Development of Wireless Telephony.

The writer has been asked on several occasions how the wireless telephone came to be invented. In November, 1899, shortly prior to the delivery of my previous paper,[84] while experimenting with the receiver shown in figure 3 of that paper, I made some experiments with a Wehnelt interrupter for operating the induction coil used for sending.

In the receiver mentioned the ring of a short-period Elihu Thomson oscillating current galvanometer rests on three supports, i. e., two pivots and a carbon block, and a telephone receiver is in circuit with the carbon block. A storage battery being used in the receiver circuit[85] it was noticed that when the sending key was kept down at the sending station for a long dash the peculiar wailing sound of the Wehnelt interrupter was reproduced with absolute fidelity in the receiving telephone. It at once suggested itself that by using a source with a frequency above audibility wireless telephony could be accomplished.

Professor Kintner, who was at that time assisting me in these experiments and to whose aid their success is very largely due, was kind enough to make the drawings for an interrupter to give 10,000 breaks per second. Mr. Brashear, the celebrated optician, kindly consented to make up the apparatus, and it was completed in January or February, 1900.

The experimental work was, however, delayed, as the writer was at that time transferring his laboratory from Allegheny, Pennsylvania, to Rock Point, Maryland, and it was not until six months later that the

84 Transactions American Institute Electrical Engineers, November 22, 1899.

85 United States patent No. 706736, December 15, 1899.

stations at that point were completed and a suitable mast was erected for trying the apparatus.

The first experiments were made in the fall of 1900 with the above mentioned apparatus, which was supposed to give 10,000 sparks per second, but which probably gave less. Transmission over a distance of 1 mile was attained, but the character of the speech was not good and it was accompanied by an extremely loud and disagreeable noise, due to the irregularity of the spark.

By the end of 1903 fairly satisfactory speech had been obtained by the are method above referred to, but it was still accompanied by a disagreeable hissing noise. In 1904 and 1905 both the arc method and another method in which the 10,000 cycle alternator above referred to was employed had been developed to such an extent that the apparatus could be used practically and sets were advertised and tendered to the United States Government.[86] The transmission was, however, still not absolutely perfect.

By the fall of 1906 the high frequency alternator had been brought to a practical shape and was used for telephoning from Brant Rock to Plymouth, a distance of 11 miles, and to a small fishing schooner, this being the first instance in which wireless telephony was put in practical use. The transmission was perfect and was admitted by telephone experts to be more distinct than that over wire lines, the sound of breathing and the slightest inflections of the voice being reproduced with the utmost fidelity.

As it was realized that the use of the wireless telephone would be seriously curtailed unless it could be operated in conjunction with wire lines, telephone relays were invented both for the receiving and transmitting ends, and were found to operate satisfactorily, speech being transmitted over a wire line to the station at Brant Rock, retransmitted there wirelessly by a telephone relay, received wirelessly at Plymouth, and there relayed out again on another wire line. On December 11, 1906, invitations were issued to a number of scientific men to witness the operation of the wireless transmission in conjunction with the wire lines. A report of these tests appeared in the American Telephone Journal of January 26 and February 2, 1907, the editor being one of the men present.

In July, 1907, the range was considerably extended and speech was successfully transmitted between Brant Rock and Jamaica, Long Island, a distance of nearly 200 miles, in daylight and mostly over land,[87] the mast at Jamaica being approximately 180 feet high.

In 1907 several European experimenters succeeded in transmitting speech wirelessly, using some of the earlier forms of the writer's are method, and some months ago the vessels of our Pacific squadron were

86 Letter of July 8, 1905; see The Electrician, London, February 22, 1907; also catalogue of 1904 and subsequent.

87 "Long distance wireless telephony," The Electrician, October 4, 1907.

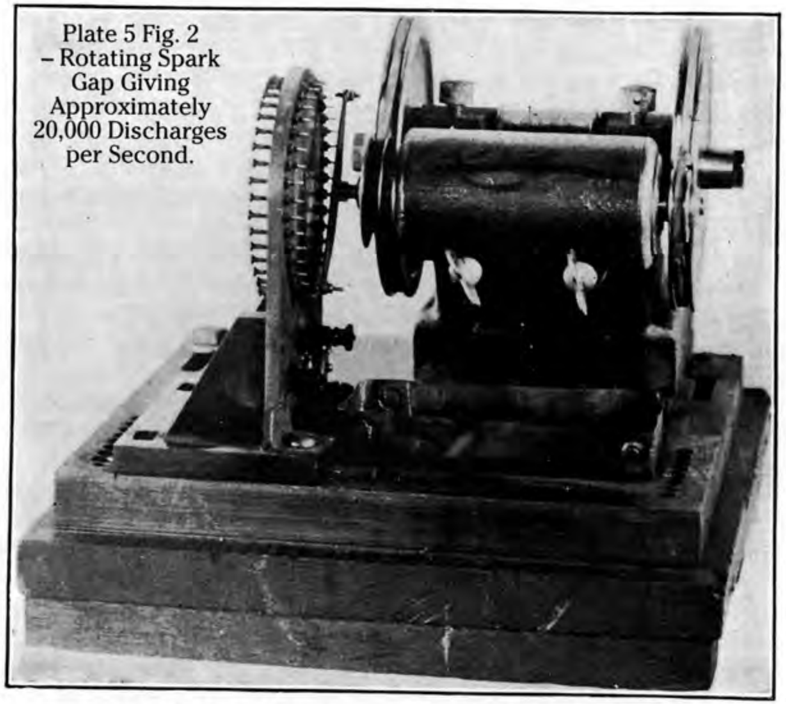


Plate 5 Fig. 2 – Rotating Spark Gap Giving Approximately 20,000 Discharges per Second.

equipped with wireless telephones, using this are method, by another American company.

METHODS AND APPARATUS.

METHODS AND APPARATUS FOR PRODUCING THE ELECTROMAGNETIC WAVES.

These have been already referred to. Plate 5, figure 2, shows a rotating spark gap giving approximately 20,000 discharges per second. This was

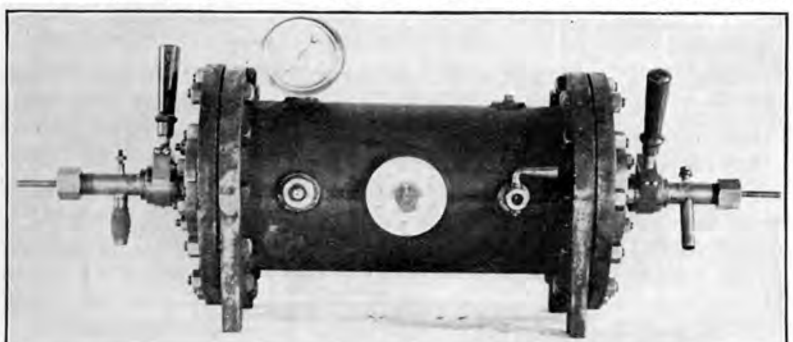


Plate 6 Fig. 1 – Apparatus for Operating Electric Arc in Gas under Pressure and in Vacuum, and the Critical Distance Arc.

Plate 6 Fig. 2 – Apparatus for Operating Electric Arc in Gas under Pressure.

connected to a 5,000-volt source of direct current. The terminals are of 40 per cent platinum-iridium. In operation the apparatus is arranged to charge a condenser to a definite potential and discharge it.

Plate 6 shows forms of apparatus for operating the arc in a gas under pressure.

The apparatus of figure 1 on plate 6 is also used for the are in vacuum and the critical distance arc.

Plate 7, figure 1, shows a multiple gap with rotating electrodes, brass, amalgamated zinc, and graphite being used.

Plate 7, figure 2, shows a multiple are gap with electrodes of different materials, the upper terminals being water cooled.

Plate 8, figure 1, shows a condenser dynamo.

Plate 8, figure 2, shows a general view of one type of high-frequency

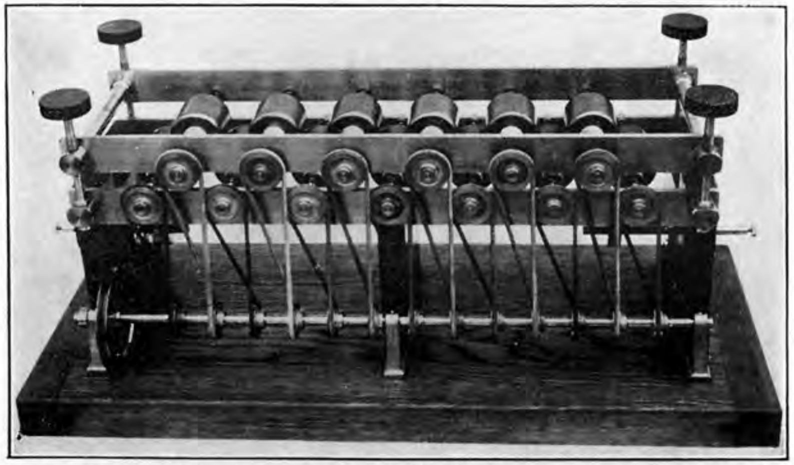
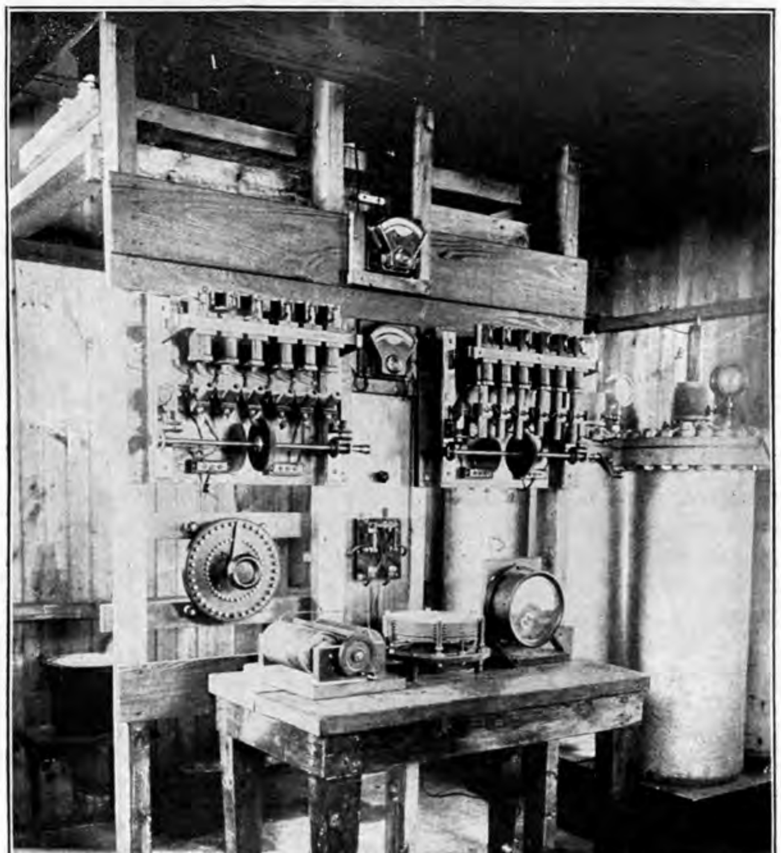


Plate 7 Fig. 1 – Multiple Gap with Rotating Electrodes; Brass, Amalgamated Zinc and Graphite Used. (below) Plate 7 Fig. 2 – Multiple Arc Gap with Electrodes of Different Materials; Upper Terminals Water Cooled.



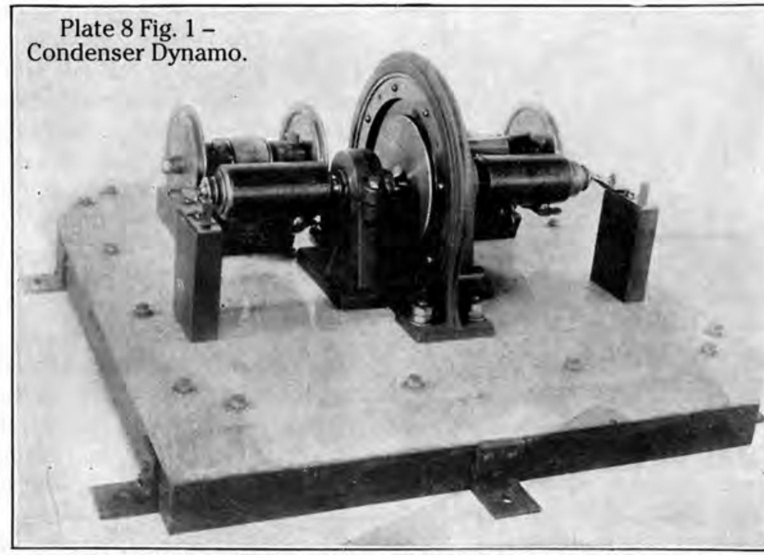
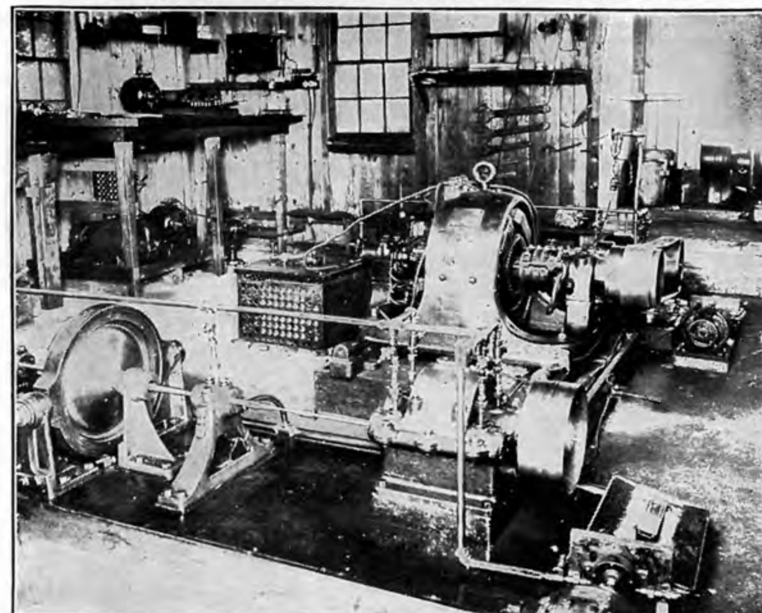


Plate 8 Fig. 1 – Condenser Dynamo.

(below) Plate 8 Fig. 2 – Type of High-Frequency Alternator.



alternator. It is driven by a motor and a De Laval gear. It has been operated at 96,000 cycles per second, but is generally run at 81,700.

Plate 9, figure 1, shows a field disk; it is 12 inches in diameter and there are 300 slots on it.

Plate 9, figure 2, shows the armature and field coils. There are 600 armature slots, each containing two turns of 13 mil wire. The field current is 5 amperes. The resistance of the armature is 6 ohms; it gives

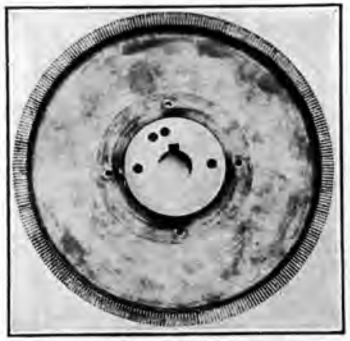


Plate 9 Fig. 1 – Field Disk, 12 Inches in Diametter, 300 Slots.

160 volts and about 7 or 8 amperes. Other armatures have been constructed having a resistance of 4 ohms. For some work double armatures are used giving about 270 volts. The output of the single-armature machines at 81,700 cycles is approximately 1 kilowatt. The output of the double-armature machine is approximately 2 kilowatts.

Other types of high-frequency alternators are under construction. One type shown in plate 10, figure 1, is designed for use on shipboard. The armature disk is 6 inches in diameter and two armatures are used. It is arranged to be mounted on gimbals and to be driven by a steam turbine connected to the steam pipe by flexible, armored steam hose. The frequency is about 100,000 and the output about 3 kilowatts.

Another type, which is at present being constructed by Mr. Alexanderson, to whose efforts the success of this type of generator is largely due, is designed to have an output of 10 kilowatts. Designs have

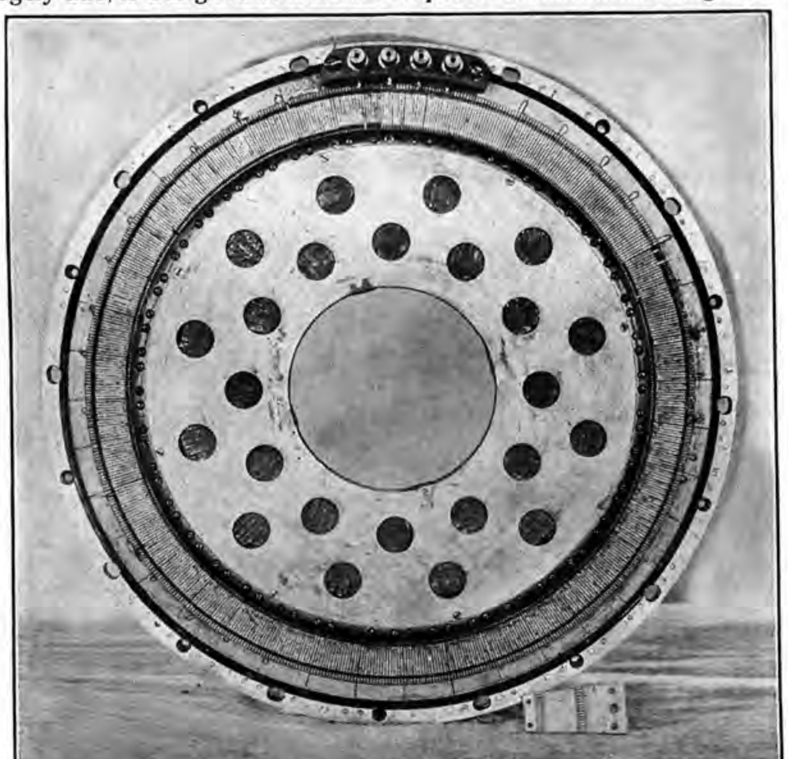


Plate 9 Fig. 2 – Armature and Field Coils, 600 Slots.

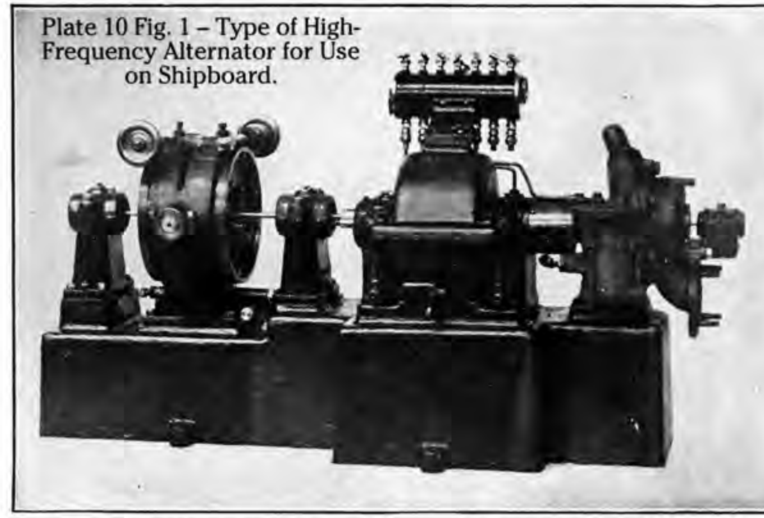


Plate 10 Fig. 1 – Type of High-Frequency Alternator for Use on Shipboard.

been made for a generator of still larger size, with a calculated output of 50 kilowatts and a frequency of 50,000. This machine is intended for trans-Atlantic work.

For some of these machines, instead of driving by gear or steam turbine, a special 2-cycle motor has been devised, to operate at a frequency of 500 cycles per second.

The high frequency alternator method is believed to possess a number of advantages over other methods, inasmuch as it is set in operation by merely opening a steam valve and has no complicated electrical apparatus or circuits of any kind. The speed is regulated by the steam pressure, this being accomplished by an electrically operated reducing valve.

For measuring the frequency various speed indicators have been tried, but it has been found that the best way is to use a resonant circuit, with an ammeter (shown in plate 11) in it,[88] this being an extremely sensitive means of indicating the frequency, and in addition affording a means of automatically keeping the speed constant to a small fraction of a per cent. The reducing valve is adjusted so that if left to itself the machine will run slightly above speed[89] As soon as it reaches one-tenth of 1 per cent higher than its designed speed, the resonance begins to fall, and a contact is opened which slightly throttles the steam. In this way the frequency is kept varying between the limits of one-tenth of 1 per cent above speed and one-tenth of 1 per cent below speed. Where the drive is electric instead of by turbine, a storage battery is used to drive the two-phase generator, and even better results may be obtained as regards regulation than with steam.

88 Electrical World and Engineer, November 11, 1899.
89 Since writing the above, my attention has been called to the fact that the general method of governing by resonance was invented and patented by Kempster B. Miller, United States patent No. 559187, February 25, 1896.

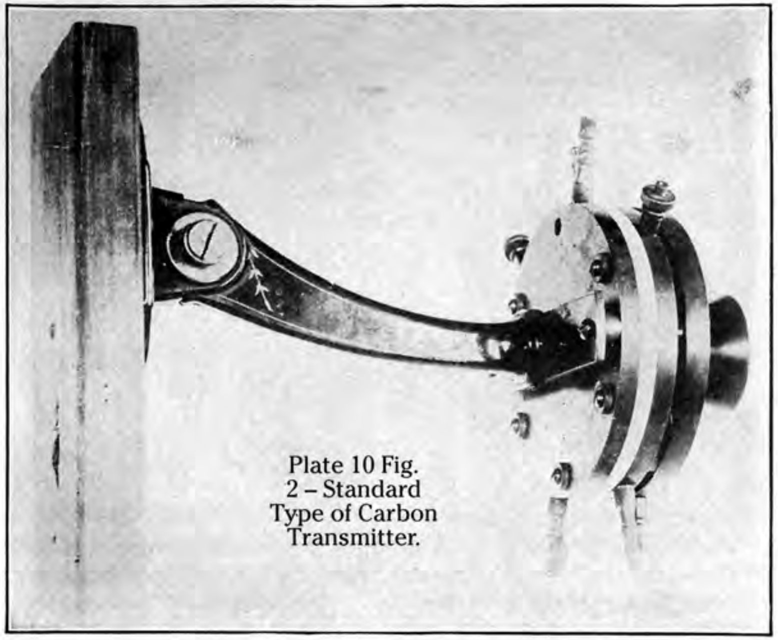


Plate 10 Fig. 2 – Standard Type of Carbon Transmitter.

TRANSMITTERS.

The types of transmitters most commonly used are the carbon transmitter and static transmitter, and the carbon transmitter relay.

Plate 10, figure 2, shows the standard type of carbon transmitter.

It was found that the ordinary carbon transmitter was unsuited for wireless telephonic work, on account of its inability to handle large amounts of power. A new type of transmitter was therefore designed, which the writer has called the "trough" transmitter. It consists of a soapstone annulus to which are clamped two plates with platinum-iridium electrodes. Through a hole in the center of one plate passes a rod, attached at one end to a diaphragm and at the other to a platinum-iridium spade. The two outside electrodes are water jacketed.

This transmitter requires no adjusting. All that is necessary is to place a teaspoonful of carbon granules in the central space. It is able to carry as much as 15 amperes continuously without the articulation falling off appreciably. It has the advantage that it never packs. The reason for this appears to be that when the carbon on one side heats and expands the electrode is pushed over against the carbon on the other side. These transmitters have handled amounts of energy up to one-half horsepower, and under these circumstances give remarkably clear and perfect articulation and may be left in circuit for hours at a time. Plate 12, figure 1, shows a modified form with split back.

Plate 12, figure 2, shows a transmitting relay for strong currents. The only thing noticeable about this is that the telephone magnet is a differential one.

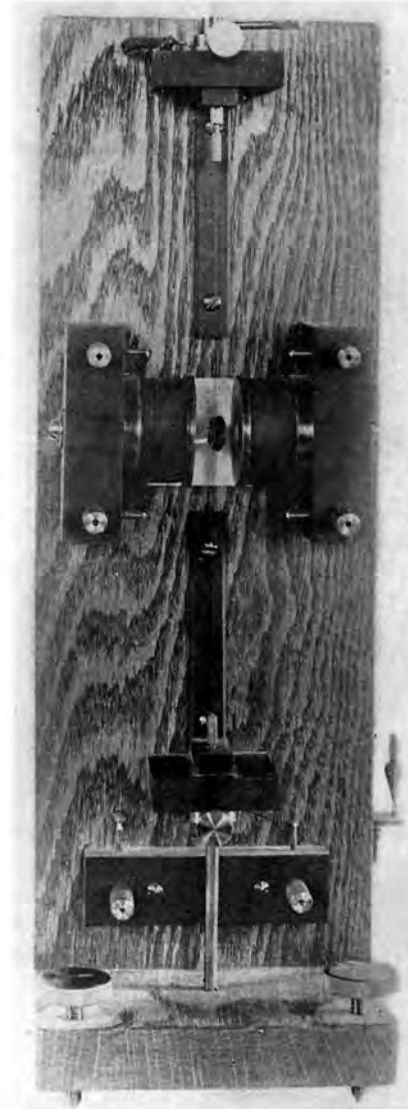


Plate 11 – Ammeter for Indicating Frequency and Automatically Regulating Speed.

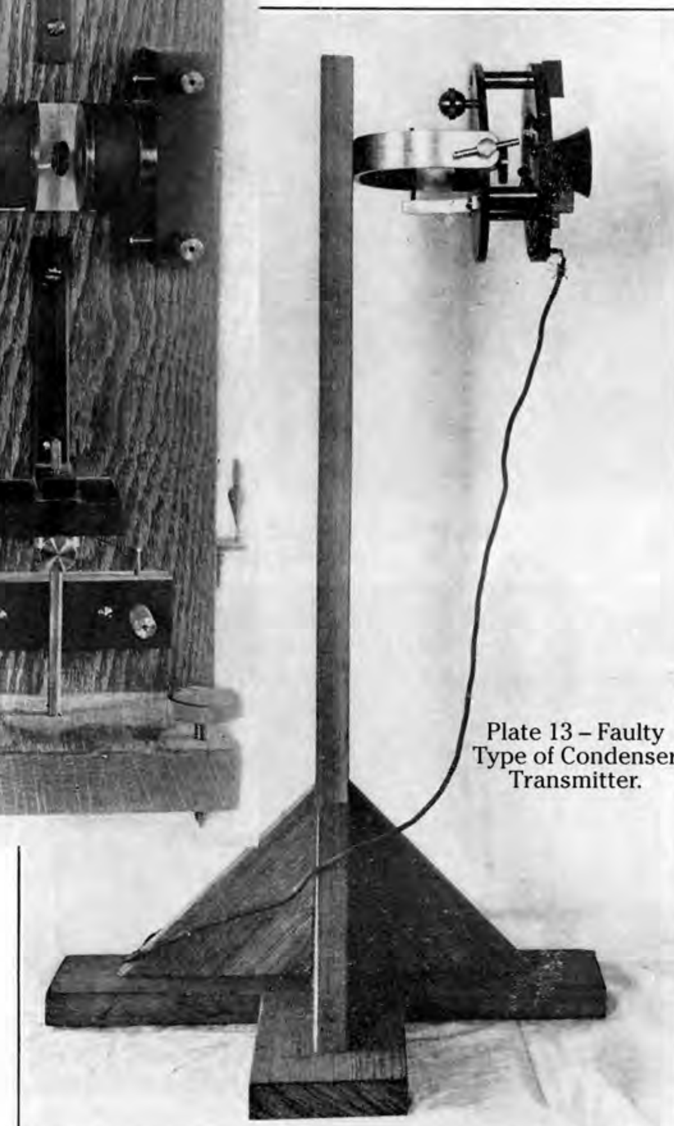


Plate 13 – Faulty Type of Condenser Transmitter.

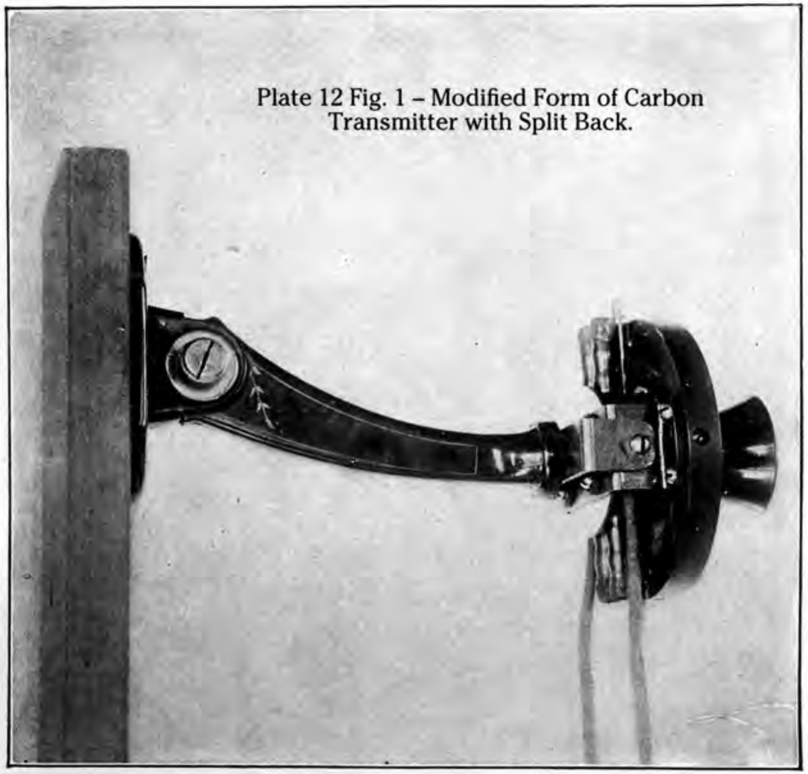
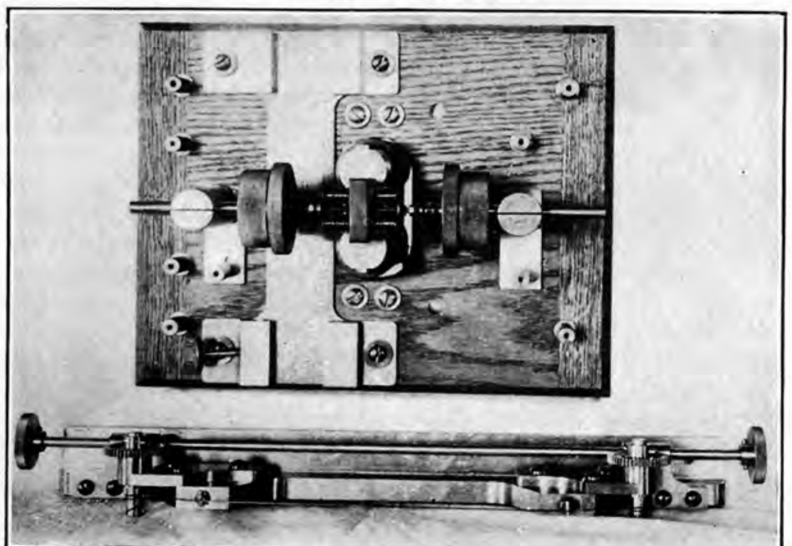


Plate 12 Fig. 1 – Modified Form of Carbon Transmitter with Split Back.

(below) Plate 12 Fig. 2 – Transmitting Relay for Strong Currents.



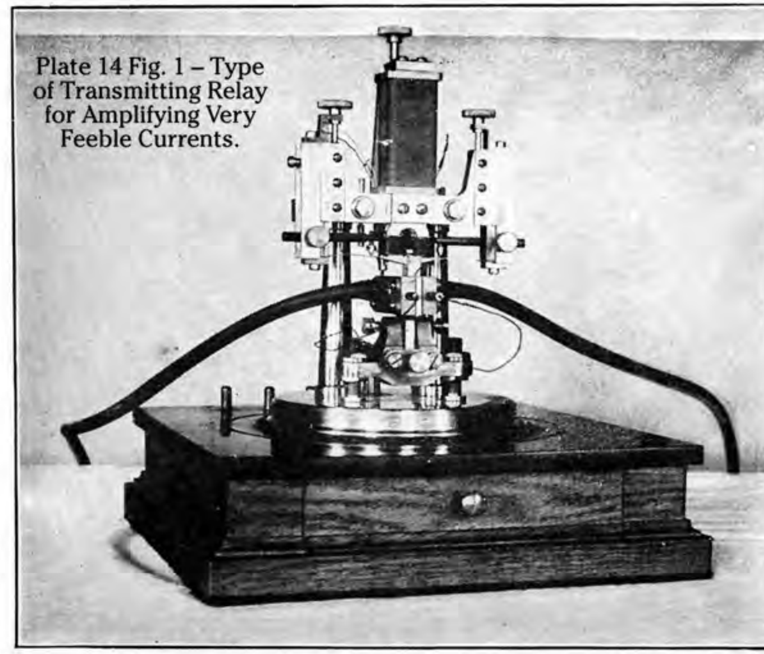


Plate 14 Fig. 1 – Type of Transmitting Relay for Amplifying Very Feeble Currents.

Plate 13 shows a type of condenser transmitter in which the vibration of the diaphragm alters the electrical capacity of the transmitter, thus throwing the circuit in and out of tune or spilling more or less energy through a leakage circuit.

Plate 14, figure 1, shows another type of transmitting relay for amplifying very feeble currents. It will readily be understood that where a person in Albany, for example, wishes to talk to another person on board a ship off New York, the wireless station being located near New York, the volume of the transmission received at New York will not be very strong, and while it may be possible to transmit it without amplification, amplification is advisable.

This receiver is a combination of the differential magnetic relay and the trough transmitter. An amplification of fifteen times can be obtained without loss of distinctness. The side electrodes of the trough are water jacketed. The successful amplification depends upon the use of strong forces and upon keeping the moment of inertia of the moving parts as small as possible. Amplification may also be obtained by mechanical means, but as a rule this method introduces scratching noises, which are very objectionable, even though comparatively faint.

Other types of transmitters have also been used, such as liquid jet transmitters, transmitters operating by closing the air gap in a magnetic circuit (plate 15, figure 1), and so changing the inductance of the oscillating circuit, etc.

Plate 14, figure 2, shows a loud-speaking telephone receiver. A small iron disk is placed opposite a nozzle through which air at high pressure

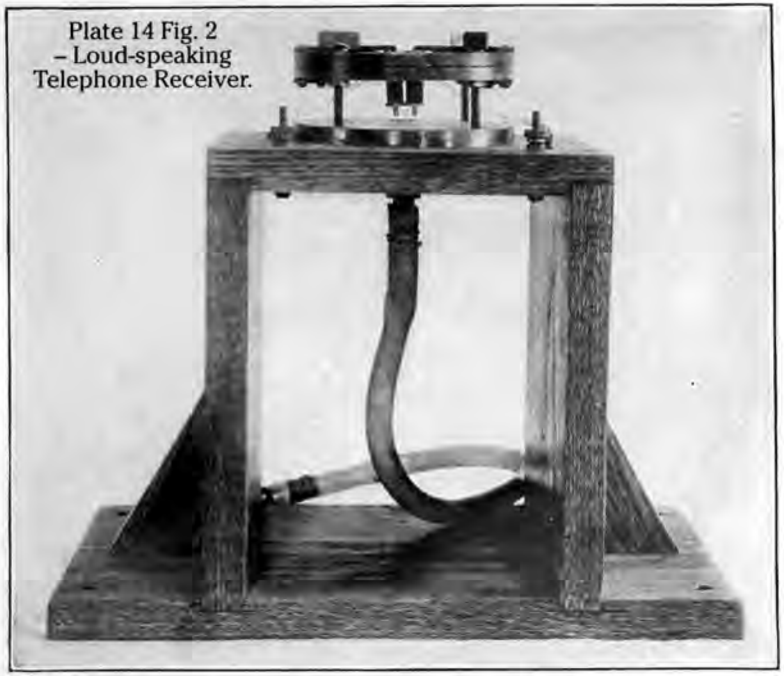


Plate 14 Fig. 2 – Loud-speaking Telephone Receiver.

is blown. As is well known, this causes the disk to be held close to the nozzle. The telephone magnets alter the position of the disk and thus produce very loud talking.

The transmitting relays are connected in the wire-line circuit in the same way as the regular telephone relay, except that in place of being inserted in the middle of the line they are placed in the wireless station and an artificial line is used for balancing. There is no difficulty met with on the wireless side of the apparatus, but on the wire-line side there are the well-known difficulties due to unbalancing which have not yet been entirely overcome. For the correction of these difficulties, therefore, we must look to the engineers of the wire telephone companies. At present the difficulties are, if anything, less than those met with in relaying on wire lines alone.

TRANSMITTING CIRCUITS.

Figure 2[90] shows a type of arc circuit.

Figure 3[91] shows a suitable type of connection for use with a high-frequency alternator.

Figure 4[92] shows a type of circuit for use with the condenser transmitter.

90 United States patents Nos. 706742, June 6, 1902, and 730753, April 9, 1903.
91 United States patent No. 706742, June 6, 1902.
92 United States patent No. 706747, September 28, 1901.

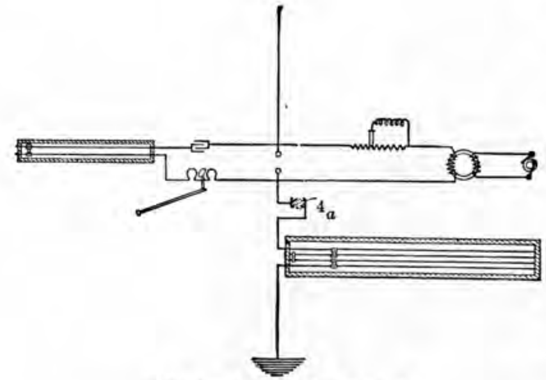


FIG. 2.—Type of arc circuit.

Figure 5[92] shows a type of circuit in which the modulation is accomplished by changing the inductance of one of the oscillating circuits.

As a matter of fact the transmitter may be placed almost anywhere in the circuit between the arc or dynamo and the antenna, or between the arc or dynamo and ground, or in the transformer circuit, or in shunt to an inductance or capacity, the results obtained in all cases being indistinguishable. The sole criterion of success seems to be that the transmitter should be capable of handling the energy and the circuit should be properly adjusted. Some success has also been attained by placing the transmitter in the field of the dynamo,[93] but this method requires very careful designing of the field circuit.

FIG. 3.—Type of connection with high-frequency alternator.

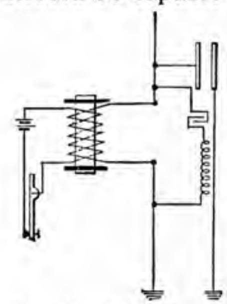


FIG. 4.—Circuit for use with condenser transmitter.

Receivers. – The receiver which the writer has found most satisfactory for general purposes is the liquid barretter. Plate 15, figure 2, and plate 16, figure 1, show this receiver. It consists of a fine platinum wire, about a ten-thousandth of an inch in diameter, immersed in nitric acid. Tests made with this receiver show that it responds without apparent loss of efficiency to notes as high as 5,000 per second. Some very careful measurements recently made by my assistants, Messrs. Glaubitz and Stein, give the following results:

Voltage of high frequency circuit necessary to produce readable signals, 15 X 10^{-5} volts.

Ohmic resistance of receiver, 2,500 ohms.

Value of high frequency current necessary to produce readable signals, 6 X 10^{-5} amperes.

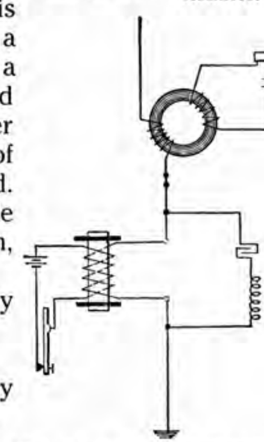


FIG. 5.—Circuit; modulation accomplished by changing inductance of one of oscillating circuits.

93 United States patent No. 793649, March 30, 1905.

Electromagnetic wave energy required to produce audible note for period of one second, 1 X 10^{-4} ergs.

The telephone used for detecting the signals had a resistance of approximately 1,000 ohms. Some measurements were made to determine the change of current in the telephone circuit by using a sensitive galvometer in series with the telephone, but the results obtained were obviously too low, possibly on account of the electrostatic capacity of the turns of the galvanometer with respect to each other. It will be noted that the amount of electromagnetic wave energy necessary to produce a signal is considerably less than that given in a previous note.[94] The difference is possibly to be attributed to improvements in adjustment and operation.

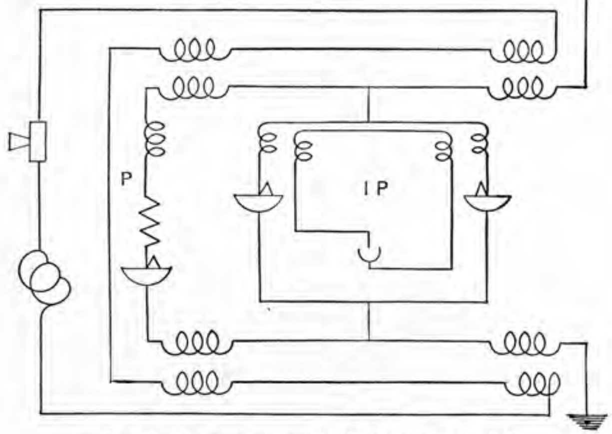


FIG. 6.—Balance method with phantom aerial P.

The above measurements were taken by shunting the barretter across a piece of straight resistance wire in series with a hot-wire ammeter, to determine the voltage necessary, and by introducing resistance in series with the barretter to determine the resistance of the barretter. The figures were also checked in a number of other ways and very concordant results were obtained, so that it is believed they may be relied upon.

The previously mentioned thermoelectric receivers or rectifiers of Doctor Austin and Mr. Pickard, shown in plate 16, figure 2, and the vacuum tube receivers of Fleming, De Forest, and Cooper-Hewitt also act very satisfactorily. The fact that the writer has not been able to get as good results from them may be due to greater familiarity with the liquid barretter and heterodyne receiver.

Plate 17, figures 1, 2, and 3 show forms of heterodyne receiver adapted for use for telephonic work.

Receiver connections. – Where the wireless telephone is operated by first talking into the transmitter and then throwing a switch and listening, the usual wireless telegraphic connections are used. This has been found in practice to be very inconvenient, however, and several methods have therefore been devised for talking and listening simultaneously, which methods can, of course, also be applied to duplex wireless telegraphy.

94 Electrical World and Engineer, October 31, 1905.

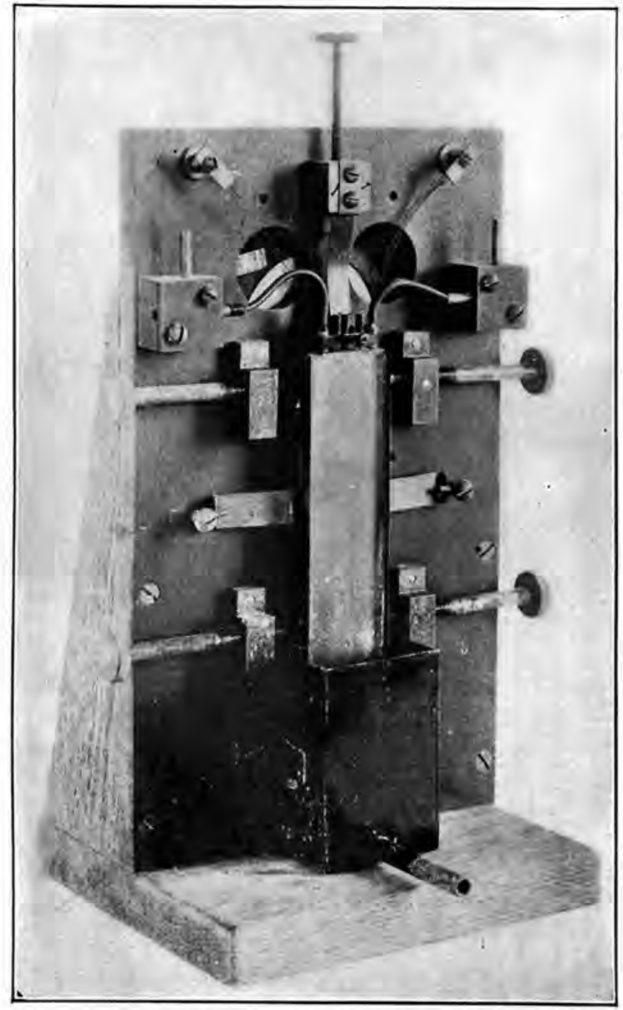
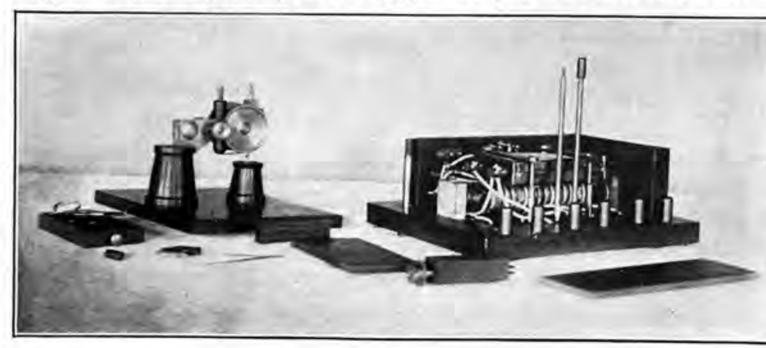


Plate 15 Fig. 1 – Type of Transmitter Operating by Closing Air Gap in Magnetic Circuit. (below) Plate 15 Fig. 2 – Liquid Barretter Receiver.



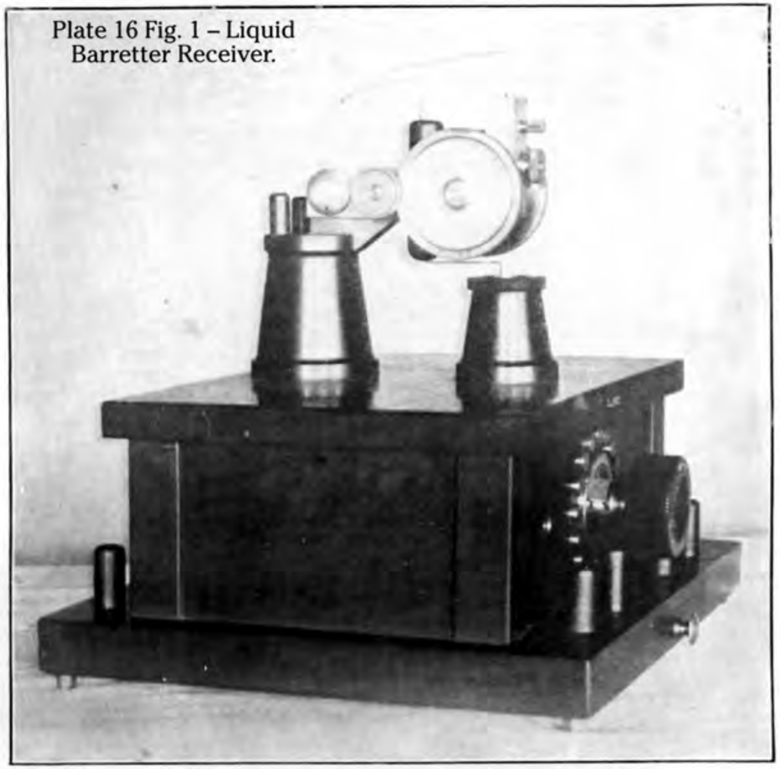


Plate 16 Fig. 1 – Liquid Barretter Receiver.

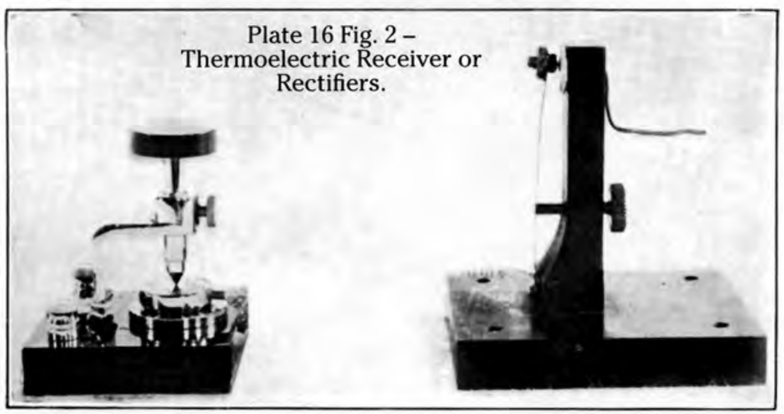


Plate 16 Fig. 2 – Thermoelectric Receiver or Rectifiers.

Among these methods may be mentioned the commutator method[95] and the balance method.[96]

The former method is fairly well known and consists in rapidly connecting alternately the transmitter and receiver. The balance method consists in using a phantom aerial as shown in figure 6, where

95 United States application, No. 3501199, December 31, 1906.
96 United States application, No. 366528, April 5, 1907.

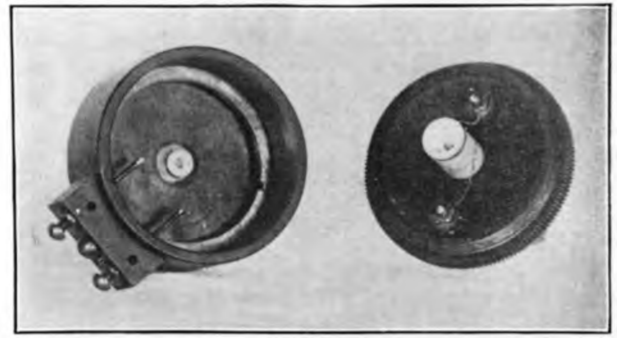


Plate 17 Fig. 1 – Form of Heterodyne Receiver Adapted for Use in Telephone Work. (below) Plate 17 Fig. 2 – Form of Heterodyne Receiver Adapted for Use in Telephone Work.

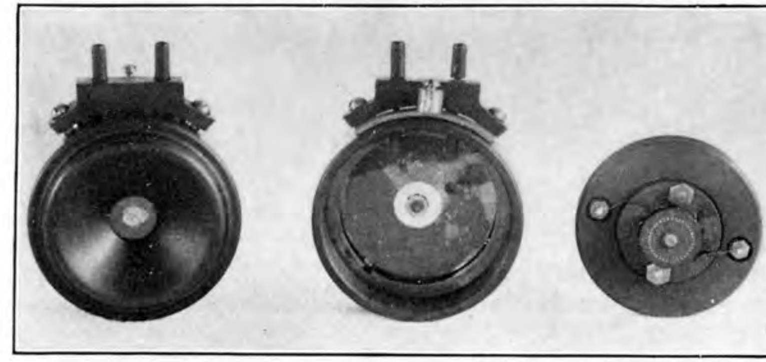


Plate 17 Fig. 3 – Form of Heterodyne Receiver Adapted for Use in Telephone Work.

P is a phantom aerial, the circuit having such capacity inductance and resistance as to balance the radiating antenna. The apparatus is shown in plate 18, figure 1.

In order entirely to cut out disturbances in the receiver while sending, an interference preventer, I P, the elements of which are shown in plate 18, figure 2 and plate 19, figure 1, is used in the receiving circuit.

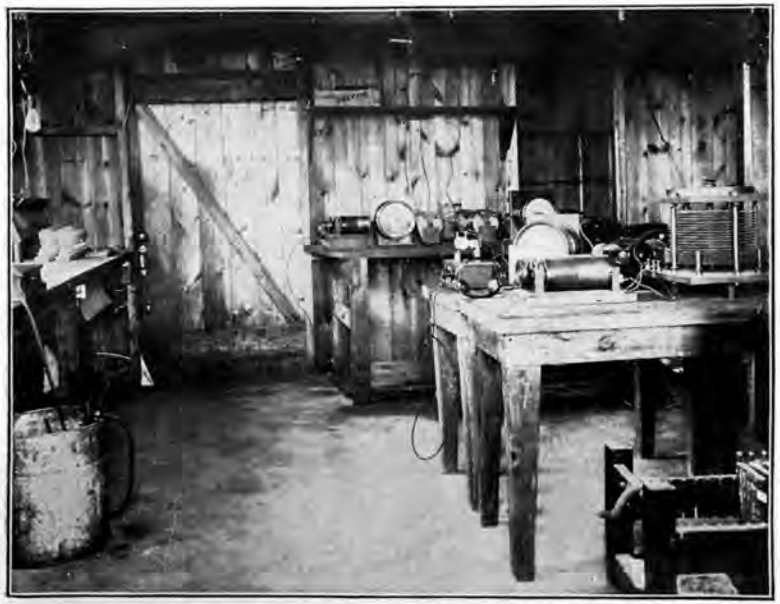


Plate 18 Fig 1. – Apparatus for Balance Method of Talking and Listening Simultaneously.

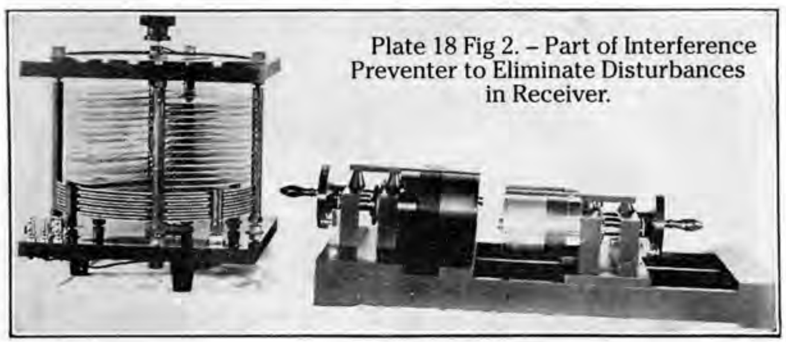


Plate 18 Fig 2. – Part of Interference Preventer to Eliminate Disturbances in Receiver.

Plate 19 Fig 1. – Part of Interference Preventer to Eliminate Disturbances in Receiver

It may be here mentioned that balance methods work much better with wireless telephony and telegraphy than with line telephony and telegraphy, for the reason that the radiation resistance of an antenna is absolutely definite and is not affected by the weather, as are line circuits. Consequently, the balance can be made very sharp and once made does not need to be altered.[97] Of course, half the energy is lost, but this is a matter of practically no importance, as the cutting down of the strength of a telephonic conversation to one-half is as a rule hardly noticeable, especially where there are no line noises or distortion of the speech through capacity effects.

Receiving station relay. – The receiving station relay is similar to the transmitting relay shown in plate 14, figure 1. The same remarks apply to its use in connection with wire lines as to the transmitting relay.

Operation.

As will be realized from the above, the operation of a wireless telephone system is very simple. The operator merely throws his switch to the position for telephoning and talks into an ordinary transmitter and listens in an ordinary telephone receiver. When the duplex method is used, as is always advisable, the conversation proceeds exactly as over an ordinary telephone line. Plate 20 shows a phonograph transmitting music and speech wirelessly. Plate 19, figure 3, shows talking by relays from a local circuit.

I believe I am correct in saying that the transmission by wireless telephone is considerably more distinct than by wire line and that the fine inflections of the voice are brought out much better. This, I presume, is due to the fact that there is no electrostatic capacity to distort the speech, as in the case of wire lines, though I think the effect is also partly due to the absence of telephone induction coils with iron cores. Possibly some of the gentlemen present have witnessed the operation of the wireless telephone transmission between Brant Rock and Plymouth and

97 This method may, of course, be used for duplex working in wireless telegraphy. As some question has been raised in regard to the capacity of wireless telegraph lines the writer would say that he has received messages at the rate of 250 words per minute by wireless and is now experimenting with apparatus designed to give 500 words per minute. With duplexing this gives 1,000 words per minute or 60,000 words per hour. The manager of one of the largest cable companies has stated (London Daily Mail, September 24, 1907) that all the trans-Atlantic cables together send 24,000 words per hour. It would appear, therefore, that if capacity alone be considered a single station on each side of the Atlantic can handle more traffic than all the present cables. It should be pointed out, however, that the mere ability to handle the messages is not sufficient and that unless the wireless telegraph companies obtain land facilities equal to those at present enjoyed by the cable companies they can not handle the traffic as efficiently, i. e., can not deliver a message from New York to an individual in London and receive a reply in the same time. Plate 19, figure 2, shows a Wheatstone transmitter used for the test referred to.

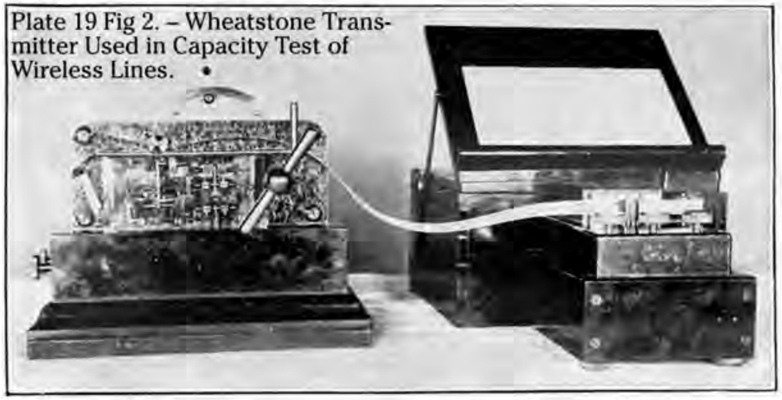


Plate 19 Fig 2. – Wheatstone Transmitter Used in Capacity Test of Wireless Lines.

between Brant Rock and Brooklyn. If so, I think they will bear me out in saying that the transmission was clearer than over wire lines.

As a rule, there is absolute silence in the wireless telephone receiver except when talking is going on, though of course the usual noises may be heard if persons are walking across the room, etc. This makes listening less of a strain than when talking over wire line. Even during severe atmospheric disturbances the talking is not interfered with to any noticeable extent, provided, of course, that an interference preventer is used.

A comparative test was made with talking between Brant Rock and Brooklyn by wireless and by wire telephony. The talking over the wire line was done from a long-distance station in Brooklyn. The wireless transmission was considerably the better. The fact that the wire line included in its circuits a cable from New York to Brooklyn was of course a disadvantage, but even allowing for this, practice and theory appear

Plate 19 Fig 3. – Talking by Relays from a Local Circuit.

to be in agreement to the effect that transmission by wireless telephony over long distances is better than by wire line.

This method should be of especial value to independent telephone companies, which have their local exchanges, but no long-distance lines, especially since no franchises or rights of way are necessary.

Possibilities.

Local Exchanges.

There is no immediate prospect that wireless telephony will take the place of local exchanges. The difficulty in regard to the number of tunes can be overcome, but the fact remains that high frequency oscillations can not be transmitted over wire, and hence each subscriber must have his own generating station. At the present time no method is known which would be practical if placed in the hands of a subscriber. If such means should be found it would be very convenient to call up directly instead of through an exchange, but as I see it there are no immediate prospects of this.

Long-distance Lines.

I believe, however, that there is a field for wireless telephony for long-distance lines. The present long-distance lines are very expensive to construct and maintain, and a storm extending over any considerable section of country inflicts considerable loss on the telephone companies. Moreover, the distance of transmission is limited by the electrostatic capacity of the line, as I understand it. Wireless telephony would have the following advantages:

1. The initial cost would be very much less than that of wire lines.
2. The maintenance would be practically negligible in comparison.
3. In case of any breakdown it would be right in the station and not at some unknown point outside on the line.
4. The depreciation would be comparatively small.
5. The number of employees required would be smaller.
6. The transmission is better, and as there is no distortion of the speech the working distance is, it is believed, considerably greater.
7. The flexibility is greater. With wire lines a telephone company may not be able to give a Boston subscriber a line to New York, while having lines from Boston to Chicago and from Chicago to New York free. Operating wirelesly the wireless circuit normally used for operating between New York and Chicago and between Boston and Chicago could be used to operate from Boston to New York.
8. No right of way need be purchased, and franchises, it is believed, are not necessary.

It will be noted that I have not mentioned any disadvantages of wireless telephony for long-distance work. I presume this is because I am not a telephone engineer. I hope the defects will be discussed by the experts who are familiar with telephone operation and therefore better, able to point them out. Before leaving this part of the subject I would say that I think the question of interference has been worked out to such an extent that no serious difficulty need be feared in that direction.

Transmarine Transmission.

Wireless telephony is peculiarly suited for this class of work. Pupin's ingenious and beautiful method has been successful at Lake Constance, Switzerland, I believe, but even assuming that deep-sea cables of this type could be laid and operated successfully, they would nevertheless be very much more expensive than wireless telephone stations. It is believed that wireless telephony will come into extended use for this purpose. Even without further development telephonic communication could be established between Norway or Denmark or Germany or Spain and Great Britain; between Sardinia and Corsica and France and Italy; between France and Algeria; between Australia and Tasmania and New Zealand; between the United States and Cuba and Porto Rico, etc., were it not that it is at present forbidden by law.

As regards telephonic communication between England and America, my measurements show that this should be possible with an expenditure of approximately 10 kilowatts and suitably large towers, say 600 feet high, or with some of the new forms of antenna. Whether such a transmission would be commercially valuable or not is another matter. Personally I do not see that it would, but when I remember that at the time when the telephone was first being introduced a number of eminent business men decided that the house-to-house printing telegraph would be more of a success commercially than the telephone, for the reason that no one would want to do business unless he were able to have a record of the transaction, I must admit that there is a possibility of my being mistaken in this.

Wireless Telephony from Ship to Ship.

Here, of course, wireless telephony occupies a unique position. Wireless telegraphy has the disadvantage that a telegraph operator must be carried. The additional expense is an objection in many cases. The proposition that the captain or mate should also be a telegraph operator has not met with favor. Anybody, however, can operate the wireless telephone and almost every vessel carries an engineer capable of repairing the electrical apparatus in case of accident. The final arrangement will, I believe, be this; that passenger vessels will carry a telegraph operator and use the telephoning apparatus for ordinary work and for telegraphing where it is desired to communicate over long distances. Other vessels will use the telephone alone.

Wireless Telephone from Ship to Local Exchange.

This also will, I think, have considerable value, as enabling the captain of a vessel to communicate, by relaying over the wire line, with the owner of the ship, or enabling a passenger on a vessel to communicate with friends on shore.

Range of Wireless Telephony.

Atmospheric Absorption.

The great obstacle to long distance wireless telegraphy and telephony is atmospheric absorption. For short distances up to 100 miles in the Temperate Zone there is little difference between the strength of the signals at one time of the day and another. As soon as the distance is increased much over 100 miles for the Temperate Zones and 40 or 50 miles for the Tropics the signals at night are very irregular and there is great absorption during the daytime. The daylight absorption may be so great that less than a tenth of one per cent of the energy transmitted gets through. Some nights will be as bad as daytime, while on other nights there will be apparently no absorption.

Figure 7 is a curve showing the strength of the messages transmitted between Brant Rock, Massachusetts, and Machrihanish, Scotland, at night, during January, 1906. Nothing at all was received that month during daytime.

The change in the strength of the signals is very sudden. In working from Brant Rock to Porto Rico, a distance of 1,700 miles, the strength of the signals with short wave lengths would fall off to one one-thousandth of their former value during a period of less than fifteen minutes, while the sun was rising.

Early experiments showed that the absorption was greater as the wave length was increased and the effect was at first attributed to absorption in the neighborhood of the sending station, and was thought to increase

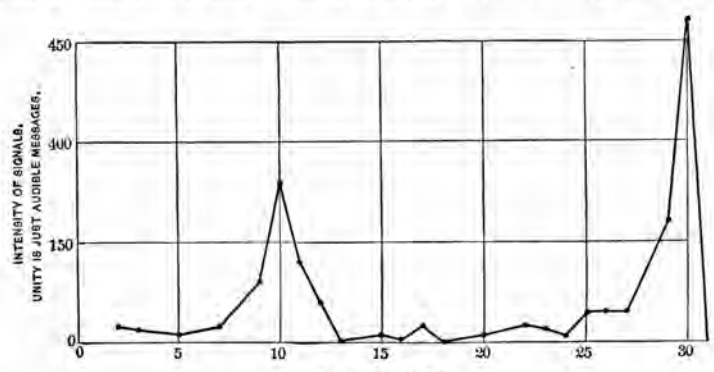


Fig. 7.—Curve showing variation of intensity of transatlantic messages for the month of January, 1906.

continuously with the wave length.[98] This fluctuating absorption at one time appeared to place a fundamental obstacle to commercial wireless telegraphy, as telegraph engineers will easily appreciate the impossibility of operating telegraph systems with circuits where the strength of the received signals may fall to one thousandth of its value or rise to a thousand times its value in the course of a few minutes.

It was therefore considered absolutely essential, in order to decide whether long-distance wireless telegraphy was commercially possible or not, to investigate this phenomenon fully. As a preliminary, the station at Brant Rock sent signals to four or five other stations at varying distances and comparative readings were taken. The following table shows the general character of the results obtained:

Station.	Distance.	Strength of signals received on worst nights.[a]
Company's cottage	200 yards	1,000
Lynn	30 miles	1,000
Schenectady	170 miles	500
Philadelphia	270 miles	300
Washington	400 miles	150
Machrihanish	3,000 miles	1

[a] Strength of unabsorbed signals taken as 1,000.

These experiments proved conclusively that the absorption did not take place in the neighborhood of the sending station, because the strength of the signals received at near-by stations was the same during the day as during the night, while there was great variation in the strength of signals received at stations farther away.

It was also found that the absorption at a given instant was a function of the direction as well as of the distance, since on a given night the signals received by stations in one direction would be greatly weakened, while there would be less weakening of the signals received by stations lying in another direction, while a few hours or a few minutes later the reverse would be the case.

This was thought to be connected with the coming weather conditions, but before this fact is proved a much larger amount of data must be collected. Through the kindness of the United States Weather Bureau I was enabled to obtain a chart of the magnetic variations, and on comparison of these with the absorption between the Massachusetts and Scotland stations there appeared to be a quite definite relation, i. e., the greater the absorption the greater the magnetic variation. Here also, however, much more data is needed before arriving at a definite conclusion. The fact that the absorption did not take place in the neighborhood of the sending station having thus been definitely settled the next point to be investigated was whether or not there was any way of overcoming it.

The fact that variations in the absorption occurred with extreme rapidity, the absorption increasing sometimes a hundred fold in a single

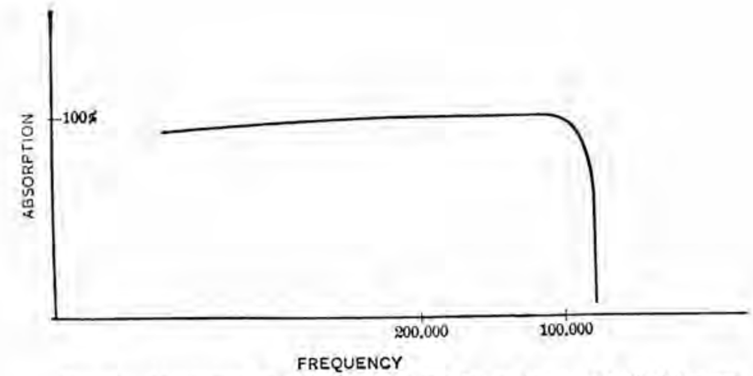


FIG. 8.—Absorption curve, tests between Brant Rock and Washington.

minute, and at night, when the effect could not be due to the sun directly, seemed to indicate that the body producing the absorption, whatever it was, was not in a state of continuity, but was broken up into masses like clouds.[99] This also was in accordance with some experiments made in Brazil in 1905.

From optical theories it is known that where the absorption is produced by conducting masses of a more or less definite size the absorption is to a certain extent selective. The next point in the investigation was, therefore, to determine whether there was any possibility of this being the fact in the case of the absorption of wireless signals.

Comparative tests were therefore made of the absorption at night and during the day between Brant Rock and Washington, with wave lengths varying from a fraction of a mile up to four or five miles. It was found that the absorption did not increase continuously with the wave length, but reached a maximum and then fell off with great suddenness.

Figure 8 shows the general character of the curve, the ordinates referring to the amount of the absorption and the abscissas to the wave frequency.

It may be noted that the absorption is a maximum at a frequency of about 200,000 per second, nine hundred and ninety-nine thousandths (0.999) of the energy being absorbed at this frequency during daylight, while for a frequency of 50,000 the absorption does not appear to be appreciable. Longer experiments, of course, might show some absorption, but in any case it is of a different order from the absorption for the shorter wave lengths.

98 A mathematical explanation of this supposed fact was given by Doctor Fleming, Principles of Electric Waves Telegraphy, pp. 617-618, 1906, the following conclusions being reached:

"Accordingly, the chief part of the weakening of the wave by sunlight is done in the neighborhood of the sending antenna, where the magnetic force H is greatest, and it is more sensible for long and powerful waves than for short and feeble ones. This agrees with the observations of Mr. Marconi."

99 Electrical Review, May 18, 1906.

Experiments were then made between Brant Rock and the West Indies, a distance of 1,700 miles, during the spring and summer of 1907. It was found that the results were of the same character, i. e., that while there was greater absorption for frequencies of 200,000 there was comparatively little absorption for frequencies in the neighborhood of 80,000, and messages were successfully transmitted in daylight with this latter frequency. No messages were received in daylight with the higher frequency, though messages transmitted from the same station and with the same power and frequency were officially reported as having been received at Alexandria, Egypt, a distance of approximately 4,000 miles.

The fact that these experiments were made during summer weather, and the receiving station was in the Tropics, and the fact that the distance, 1,700 miles, was practically the same as that between Ireland and Newfoundland, definitely settled the question as to whether long-distance wireless telegraphy was a commercial possibility or not, and the results were therefore published.[100]

Since the publication of the above results, transmission has been accomplished by means of these long waves over still greater distances during daylight. Mr. Marconi, early in October, 1907, abandoned the short-wave lengths previously used and adopted one over two units in length, and immediately succeeded in operating between Glace Bay, Nova Scotia, and Clifden, Ireland, a distance of more than 2,000 miles, the frequency being approximately 70,000. The same messages were received at Brant Rock, Massachusetts, a distance of nearly 3,000 miles.

Still more recently Captain Hogg, of the "Glacier," has written that during the southward passage of the Pacific fleet he received messages from the station at Brant Rock, Massachusetts, while off Cape Ste. Roque, Brazil, South America. The frequency used for sending was approximately 80,000, and the messages were received with the very interesting and sensitive silicon receiver invented by Mr. Pickard. This distance of 3,000 miles is the greatest yet achieved by wireless transmission during daylight, and would indicate that with the use of suitable high towers much longer distances can be reached.

Range of Wireless Telephony and Wireless Telegraphy Compared.

For the same power it is possible to telegraph to a farther distance than to telephone. Distinct speech depends upon the presence of harmonics of a frequency as high as 1,200 per second. The amplitude of these harmonics is, according to some rough experiments made by the writer, only about 1 per cent of the fundamental frequency. Consequently, with a perfectly modulated transmitter, one hundred times as much energy would be necessary to telephone a given distance as to telegraph. It fortunately happens, however, that a carbon transmitter and also the circuits in which it is used, can be so constructed as not to modulate perfectly, but can be arranged so as to accent the higher harmonics.

100 The Electrician (London), July 26, 1907.

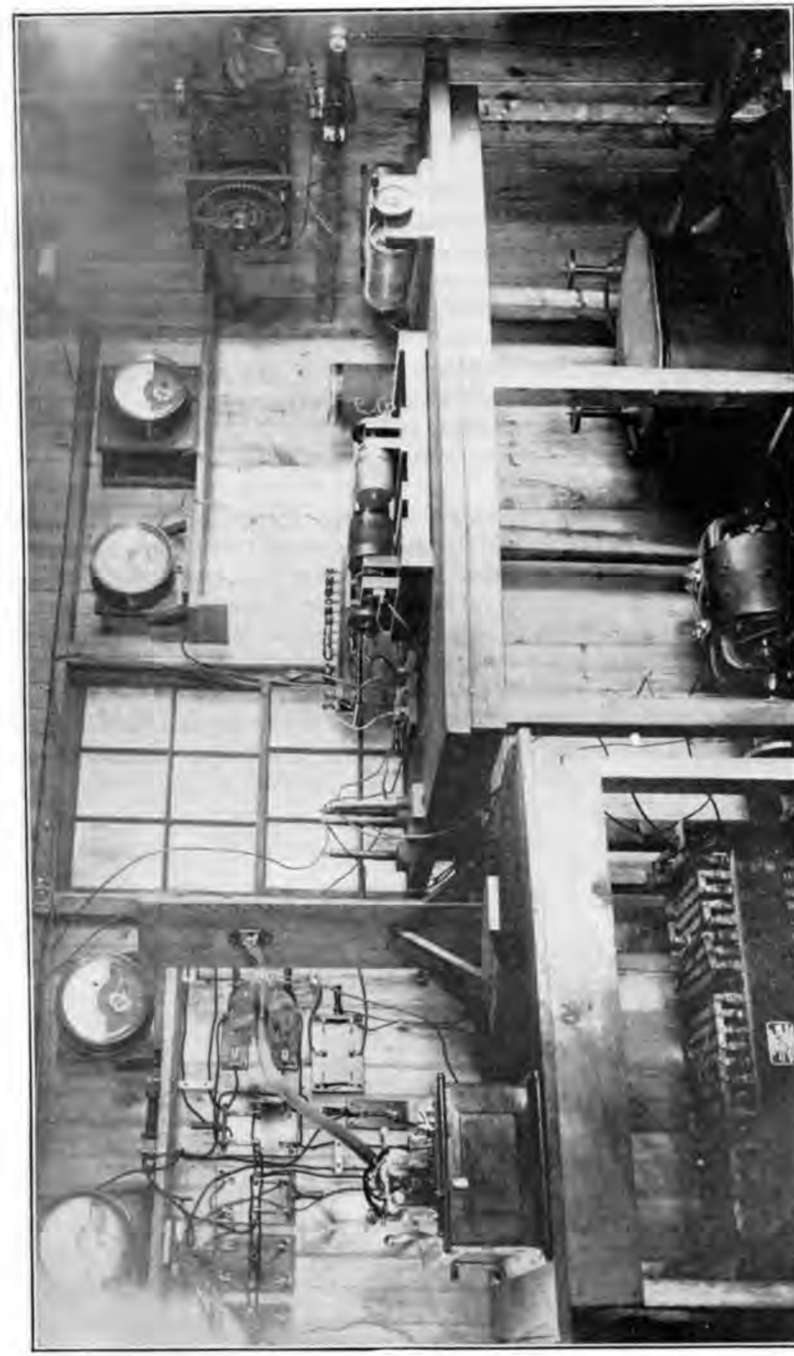


Plate 20 – Phonograph Transmitting Music and Speech Wirelessly.

With transmitters arranged for the purpose good transmission has been obtained with thirty times the energy required to produce audible telegraphic signals. By still further modification the power required has been reduced to approximately ten times that necessary for telegraphing, curiously enough without noticeably distorting the character of the speech. There is one fact, however, which prevents the ratio from being as large practically as the instruments show, i. e., speech can be satisfactorily understood with a less increase of power above a minimum audibility than telegraphic signals.

The amount of power necessary for wireless telephony may therefore be taken as approximately five to fifteen times that necessary for wireless telegraphy, i. e., under the same circumstances and for the same power the wireless telegraph will carry two to four times as far. The difference in range would be very much greater also but for the curious fact that there is much less falling off with sustained oscillations than with intermittent groups of waves, even though the frequencies are identical.

This fact has been repeatedly determined by sending between Brant Rock and Brooklyn on the same frequency, using in the one case spark-produced trains of waves and in the other the high-frequency dynamo. The difference in the falling off for the same frequency and energy is very great, but further work is necessary before anything very definite can be said about it or the reasons finally determined.

[Mr. Fessenden concludes his article with a discussion of the difficulty of securing governmental authority and legislation for the development and operation of wireless telegraph systems by private corporations.]