RADIODYNAMICS

THE WIRELESS CONTROL OF TORPEDOES AND OTHER MECHANISMS

BY

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112 ILLUSTRATIONS

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PREFACE

In the preparation of this work the author has endeavored to present in an orderly and instructive fashion the most important material concerning the history, methods and apparatus of Radiodynamics, the art of controlling distant mechanisms without artificial connecting means.

He has aimed especially at a treatment of his subject-matter that would be intelligible to the general reader without sacrificing the technical exactitude which makes scientific work of value to the trained engineer.

The chief recent developments in this new art have been of a military nature, and for this reason the volume is devoted for the most part to the torpedo-control applications of Radiodynamics.

It is hoped that the book may prove interesting to the general scientific reader, as well as to the trained engineer, and to those concerned in the purely military applications and possibilities of wirelessly-controlled mechanisms.

The author desires here to thank the many friends who have generously assisted him in collecting his materials. He desires especially to express his obligation to Professor M. H. Liddell, of Purdue University for his advice and assistance in the preparation of the book for press.

B. F. M.

Lafayette, Ind.,
August, 1916.

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RADIODYNAMICS

CHAPTER I

HISTORICAL

From earliest times methods of conveying intelligence to a distance have been universally known and utilized. Fleet-footed runners, fires and torches by night, and smoke by day as well as acoustic methods using both air and earth as conducting mediums seem to have been among the first means of comparatively distant signalling. We read of them in the Bible (Jeremiah) and in the Greek and Latin authors; their use in the far East and in Europe leaves no doubt as to their wide employment amongst civilized nations.

The Indians of America from the North to Cape Horn still use lighted fires and blanket-controlled smoke clouds to announce special tidings and convey important messages; their system of optical signalling in which the arms were used, furnished the basis for the semaphore, which toward the end of the eighteenth century came into general use in Europe. It may still be seen on any railroad. The semaphore system was still further elaborated for maritime and military purposes and today in the armies and navies of the world we have semaphore and flag signalling as a very important means of communicating intelligence to distances not in excess of a few miles. The heliograph by day and the electric searchlight by day and night can both trace their evolution to the primeval fire and torch.

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The application of electricity has revolutionized all previous methods of signalling. The phenomenon of attraction was well known to the ancients. Thales, the founder of Ionic philosophy, who lived six hundred years before Christ, noticed the effects of friction on amber, and Theophrastus, Pliny and other writers recorded similar phenomena.

In 1727 Stephen Gray, a pensioner of the Charter House, London, made an electric discharge pass over a circuit of 700 feet. Shortly after the discovery of the Leyden jar by Muschenbroek of Leyden, in 1746, Dr. Watson, a bishop of Llandaff, transmitted a charge through 2800 feet of wire. In the same year he increased the distance of transmission to 10,600 feet through wires stretched on poles erected on Shooter's Hill, London. Benjamin Franklin made similar experiments in 1748 over the Schuylkill river at Philadelphia. Le Sage of Geneva established the first telegraph system for the transmission of intelligible signals in 1774*; this system was based on electrostatic action. The next important law was discovered by Romagnesi of Trente in 1805; but attracted little attention until it was rediscovered in 1819 by Oersted. This discovery showed that a current-carrying wire is able to deflect a magnetic needle. Schweigger in 1820 discovered that the deflecting force was increased by winding the wire several times around the needle. These very important discoveries paved the way for the galvanoscope and galvanometer. Galvanoscopic or needle telegraphs were subsequently evolved.

In 1832 Schilling, a Russian, devised a single-needle telegraph using reverse currents and combinations of signals for an alphabet. Schilling's telegraph was developed by Gauss and Weber, who built a line three miles long at Gottingen.

While Prof. A. C. Steinheil of Munich was establishing a system of telegraphy in Bavaria, Gauss, the celebrated German

* Moigno's "Télégraphie Electrique," p. 59.

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philosopher and himself a telegraph inventor, suggested to him that the two rails of a railway might be used as telegraph conductors. In July, 1838, Steinheil tried the experiment on the Nurmberg-Fürth railway, but was unable to obtain an insulation of the rails sufficiently good for the current to reach from one station to the other. The great conductivity with which he found that the earth was endowed led him to presume that it would be possible to employ it instead of the return wire or wires hitherto used. The trials that he made in order to prove the accuracy of this conclusion were followed by complete success, and he then introduced into electric telegraphy one of its greatest improvements — the earth return circuit.*

Following Sturgeon's invention of the electromagnet in 1825 and the simultaneous discovery by Faraday in England and Henry in America (1831) of the laws of electromagnetic induction, Morse laid the foundations in 1836 of the present overland electromagnetic telegraph system. In the same year in England Wheatstone with W. F. Cooke still further perfected the needle telegraph and a year later put a crude system of telegraphy into actual service on the London and Blackwell Railway. In 1839 the first public line was opened by Wheatstone between Paddington and Slough, England, twenty miles of goose quills being used for insulation.

It was once supposed that Wheatstone was the original inventor of the electric telegraph, but strictly speaking it had no inventor; it is rather the result of accumulated discoveries each adding its quota to advance the invention towards perfection. The greatest achievement of Wheatstone was his automatic recording telegraph, which is extensively used for press and other long dispatches and which has attained marvelous speeds for a mechanical recorder.

* For an account of the earth return before 1838 see Fahie's "History of Electric Telegraphy to the Year 1837," pp. 343–348.

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Morse constructed his electromagnetic telegraph in 1836, and in the next few years he devised many important modifications. Congress made him an appropriation of $30,000 in March, 1843, and on the 24th of March, 1844, the first telegraph line in the United States was successfully opened between Washington and Baltimore, a distance of about 40 miles.

The electrostatic telegraph of Le Sage was probably the first instance of the control of mechanisms from a distance by the use of conducting wires. The real art of teledynamics,* however, is based on the discoveries by Romagnesi, Oersted, and Schweigger of the phenomena of electromagnetism which led up to the conception and development of the electromagnetic telegraph. Since 1836, when Morse constructed his first telegraph, no very radical changes have been made in the general scheme on which his system was based, but it has been gradually and surely developed and brought to the present stage of perfection. One very conspicuous change in detail, however, is worthy of mention. The electromagnetic sounder first used by Morse on the line between Washington and Baltimore and exhibited in the National Museum in Washington weighed one hundred eighty-five pounds. The arms were three and one-half inches in diameter and eighteen inches long, the same size of copper wire being used for the coils as for the line wire. It was then supposed that the wire of the coils and of the line should be of the same size throughout, and even down to 1860 many practical telegraphers held this view.† The sounders now used weigh about one pound and require no more than about seventy-five cubic inches of space. The coils are wound with wire much smaller than the line wire, a great increase in sensitiveness being thereby produced.

* The art of controlling mechanisms from a distance; as used here it refers only to distant control, by electrical means, with or without connecting wires.

† London Electrical Review, Aug. 9, 1895, p. 157.

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The necessity for long-distance telegraphy brought about the invention of the relay, a very sensitive form of sounder which is actuated by the weak line currents and which in turn controls the current for operating the sounder used in receiving messages. The relay is a very important part of all systems for the distant control of mechanisms as by its use practically any amount of power can be controlled. The mere pressure of the finger on a telegraph key through which a few thousandths of an ampere flow to a distant relay is sufficient to start or stop the most powerful machinery or to set off explosive charges strong enough to destroy a whole city.

Such mechanisms as electric bells and signals of various kinds, telephone and fire alarm systems, electric clocks and chimes, and time distribution systems are all developments in the art of teledynamics. Present-day automatic telephone systems, the distant control of searchlights, and the wire-controlled torpedo are examples of the wonderful possibilities along these lines.

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CHAPTER II

WIRELESS CONTROL OF MECHANISMS

Like most wonderful inventions the telegraphic transmission of signals without the aid of conducting wires is in reality not an invention, according to the popular conception of the word, but rather the result of the combined efforts of many deep-thinking scientific men extending over a period of many years. After the discovery of the galvanic current and electromagnetism in the seventeenth and eighteenth centuries the conception and development of wireless telegraphy and wire telegraphy occurred at practically the same time. It was in 1836 that Morse constructed his first telegraph; this was not put into practical operation until 1844. In 1838 Steinheil of Munich, one of the great pioneers of electric telegraphy in Europe, gave the first intelligent* suggestion of a wireless telegraph. In a paper on this subject Steinheil, explaining his theories and observations on earth conduction telegraphy, says:

"The inquiry into the laws of dispersion according to which the ground, whose mass is unlimited, is acted upon by the passage of a galvanic current appeared to be a subject replete with interest. The galvanic excitation cannot be confined

* Earlier but vague and impractical suggestions were made previous to this time. In the Bible we find: "Canst thou send lightnings, that they may go, and say unto thee, 'Here we are?'"

In 1632 Galileo wrote of a secret art by which it would be possible to converse across a space of several thousand miles through the attraction of a magnetic needle ("Galilei Systema Cosmicum." Dial. I). The "Prolusiones Academicae" of Strada, which was published in 1617, described a method of communicating at a distance by means of two pivoted magnetic needles.

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to the portions of earth situated between the two.ends of the wire; on the contrary it cannot but extend itself indefinitely and it therefore only depends on the law that obtains in this excitation of the ground, and the distance of the exciting terminations of the wire, whether it is necessary or not to have any metallic communication at all for carrying on telegraphic intercourse.

"An apparatus can it is true be constructed in which the inductor, having no other metallic connection with the multiplier than the excitation transmitted through the ground, shall produce galvanic currents in that multiplier sufficient to cause a visible deflection of the bar. This is a hitherto unobserved fact and may be classed amongst the most extraordinary phenomena that science has revealed to us. It only holds good, however, for small distances; and it must be left to the future to decide whether we shall ever succeed in telegraphing at great distances without any metallic connection at all. My experiments prove that such a thing is possible up to distances of fifty feet. For greater distances we can only conceive it feasible by augmenting the power of the galvanic induction, or by appropriate multipliers constructed for the purpose, or, in conclusion, by increasing the surface of contact presented by the ends of the multipliers. At all events the phenomenon merits our best attention, and its influence will not perhaps be altogether overlooked in the theoretic views we may form with regard to galvanism itself." *

Discussing the same subject in another publication Steinheil says: "We cannot conjure up gnomes at will to convey our thoughts through the earth, Nature has prevented this. The spreading of the galvanic effect is proportional not to the distance of the point of excitation but to the square of this distance; so that at the distance of fifty feet only ex-

* Sturgeon's "Annals of Electricity," vol. III, p. 450.

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ceedingly small effects can be produced by the most powerful electrical effect at the point of excitation. Had we means which could stand in the same relation to electricity as the eye stands to light nothing would prevent our telegraphing through the earth without conducting wires; but it is not probable that we shall ever attain this end." *

Steinheil apparently received his inspiration for this method of transmitting signals from his accidental discovery of the conductivity of the earth in the experiments on the Nurmberg-Fürth railroad. His explanation, which is somewhat nebulous and obscured by such expressions as "multipliers,"

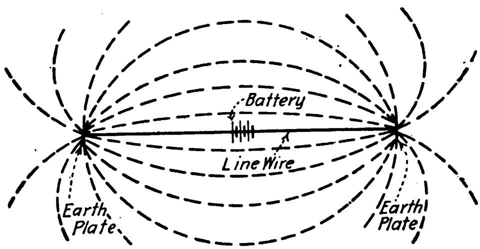

FIG. 1.

"galvanic excitation," and "galvanic induction," actually amounts to this: When two earthed conducting plates are connected to an electric battery, current flows through the earth, but not wholly through that portion directly between the plates. Instead, the current obeys Ohm's law with regard to a circuit including conductors in parallel, *i.e.*, the current in any branch is inversely proportional to its resistance. The number of parallel branches in the earth circuit is infinite, but they obey this same law. The earth between the buried plates, although having a high specific resistance, has a very great cross sectional area; this accounts for the relatively low resistance of earth returns. The current

* The electric eye of Hertz! "Die Anwendung des Electromagnetismus," 1873, p. 172.

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density, according to Ohm's law is greatest between the plates, and decreases in proportion to the distance along any line at right angles to the line joining the plates. This is shown in Fig. 1.

Steinheil's scheme was to so place another set of earth plates connected by a wire and current indicator that the current would traverse the earth between the sending and receiving plates, as shown in Fig. 2, and thus operate the receiving instrument.

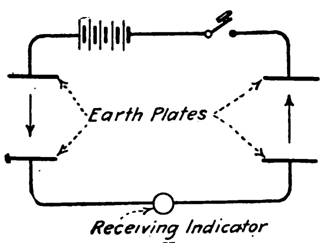

FIG. 2.

Steinheil's inability to signal over distances greater than fifty feet was, no doubt, due to the limited capacity of his current supply, the insensitiveness of his receiving indicator, and his probable ignorance of the fact that the distance between the transmitting plates should be at least three times the distance to be bridged, for the best results.

Another means of signalling without connecting wires was disclosed by Steinheil in a classic paper on "Telegraphic Communication, especially by means of Galvanism." This method is particularly interesting because of its similarity to the Photophone, invented by Alexander Graham Bell and Sumner Tainter a half century later. Describing his idea Steinheil says in part: "Another possible method of bringing about transient movements at great distances, without any intervening conductor, is furnished by radiant heat, when directed by means of condensing mirrors upon a thermo-electric pile.* A galvanic current is called into play, which in its turn is employed to produce declinations of a magnetic needle. The difficulties attending the construction of such

* In recent years thermo-piles have been developed to such an extent that the heat radiated by stars can be detected and measured. W. W. Coblentz, of the U. S. Bureau of Standards, has described, in various publications issued by

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an instrument, although certainly considerable, are not in themselves insuperable. Such a telegraph however would only have this advantage over those semaphores based on optical principles — namely, that it does not require the constant attention of the observer; but, like the optical one, it would cease to act during cloudy weather, and hence partakes of the intrinsic defects of all semaphoric methods." *

It is not probable that Steinheil ever worked this idea into usable form, as no accounts of experiments can be found, but to him is the credit really due for first (1839) suggesting a means of signalling without conducting wires by the use of radiant energy, and his was in all probability the first *radio*-telegraphic system disclosed to the world.

Another way of conveying intelligence in a manner closely related to those already given depends upon the sonorescent property of substances. The voice-controlled transmitting beam of light or heat is allowed to fall upon suitable material, such, for instance, as a sheet of hard rubber. The periodic expansion and contraction of this material, caused by the periodic variations in the intensity of the heat imparted by the beam, cause the rubber disc to reproduce the sounds made near the transmitter.

Davy's Sound-relaying System

Edward Davy, in 1838, proposed a system of wireless signalling, which, though not of any practical value, is worthy of mention because the principle involved very closely re-

that institution, micro-radiometers which are sufficiently sensitive to detect the heat of a standard candle at fifty-three miles. Edison's "tasimeter," which he devised for studying the streamers of the sun during an eclipse, is reported to have been so sensitive that a person at a distance of thirty feet could produce a perceptible effect merely by turning his face toward the instrument. The Crookes radiometer, the Duddell thermo-galvanometer, and the bolometer bridge may also be used as detectors of radiant heat.

* Sturgeon's "Annals of Electricity," Mar., 1839.

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sembles our modern schemes of relaying, which are applied in long-distance telegraphy and kindred branches of the art. The energy is transmitted a short distance to a receiver which responds, controls a local source of energy, and sends the signal on in duplicate to the next station, this operation being repeated a sufficient number of times to bridge the required distance. Davy, however, had in mind the conjoint use of sound and electricity for accomplishing this end. His plan was as follows: Stations placed about a mile apart should be fitted with powerful means of producing sound waves together with suitable means, such as our common megaphones, for directing them to the receiver and concentrating them upon some delicate form of vibratory relay. This relay would vibrate in resonance with the transmitted sound waves, close the circuit for energizing a local means of sound production similar to the first, and thus relay the signals on to the next station. Obviously, such a system was impractical in comparison with other ideas advanced at that time, principally because of the numerous stations necessary to bridge a relatively short distance, and the power required at each of these to produce sound waves of sufficient amplitude to operate the vibratory relay a mile away. John Gardner of England has developed sensitive vibratory relays with which he can control lights, motors, bells, etc., across a large room by whistling the tone corresponding in frequency to the natural period of the vibratory diaphragm or reed.*

* For other references to this subject, see Signor Senliq d' Andres, Telegraphic Journal, vol. ix, p. 126; A. R. Sennet, Journ. Inst. Elec. Eng., No. 137, p. 908. See also U. S. Hydrographic Office Bulletin of May 13, 1914 on the "Fessenden Oscillator for the Detection of Icebergs," Professor Dayton C. Miller's work with his "Phonodik," described in his book on "The Science of Musical Sounds" (Macmillan Co.), Tests on Fessenden Submarine Signalling Apparatus, Journal U. S. Art. War, Apr. 1915; see also Sci. Am., July 4, 1914—and the American Magazine, April, 1915.

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CHAPTER III

PRACTICAL WIRELESS TELEGRAPHY

The first experiments of importance with the new earth conduction telegraphy appear to have been made by Professor Morse, who, in 1842, actually transmitted signals a distance of nearly a mile across the Susquehanna river.*

In a letter to the Secretary of the Treasury which was subsequently laid before the House of Representatives, Morse says:

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

* From this we learn that Morse actually operated a wireless telegraph before his Washington-Baltimore wire system was opened for service.

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a series of experiments to ascertain the law of its passage. The following diagram (Fig. 3) will serve to explain the experiment:

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

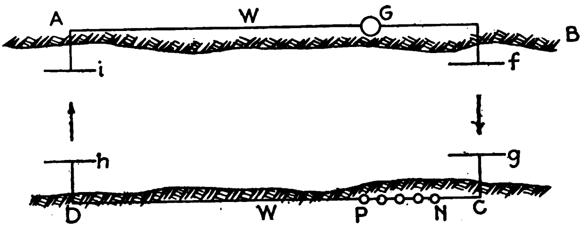

FIG. 3.

plate i, and thence around the coil of the galvanometer to plate f, across the river again to plate g, and thence to the other pole of the battery. The distance across the canal is eighty feet; on August 24 the following were the results of the experiment * . . . showing that electricity crosses the river and in quantity in proportion to the size of the plates in the water. The distance of the plates on the same side of the river from each other also affect the result. Having ascertained the general fact I was desirous of discovering the best practical distance at which to place my copper plates, and not having the leisure myself, I requested my friend, Professor Gale, to make the experiments for me." . . .

The experiments made by Professor Gale indicate that the distance between the plates along the shores should be approximately three times greater than that from shore to shore

* The table containing information only of general interest is omitted.

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across the stream, since four times the distance did not give any increase in power and less than three times the distance diminished the deflections of the galvanometer considerably. Between 1854 and 1860 James Bowman Lindsay made similar attempts at wireless telegraphy by utilizing water as the conducting medium.

With an apparatus like that of Morse, Lindsay finally succeeded in signalling across the river Tay, where it is more than a mile wide.*

J. W. Wilkins of the Cooke and Wheatstone Telegraph Co. also experimented with earth conduction telegraphy in 1845, and published the results of his investigations in the Mining Journal, March 31, 1849, under the heading "Telegraph Communication between England and France." †

Invention of the Telephone

After the invention of the telephone, in 1876, wireless telegraphy went forward with leaps and bounds. The marvelous sensitiveness of this instrument, which will give audible responses under the application of less than one-millionth of a volt of electromotive force, is largely responsible for the great progress made along these lines. Even wireless telephony was introduced.

Its use in a telegraph line running parallel to another line through which telephone conversation and singing was being carried, led to the accidental discovery of its extraordinary sensitiveness to induction currents in 1877, by Mr. Charles Rathbone of Albany, N. Y.‡

* See "Electrical Engineer," vol. xxiii, pp. 21–51; Kerr, "Wireless Telegraphy," 1898, p. 40.

† For detailed accounts of his work see Fahie's "History of Wireless Telegraphy," pp. 32–38.

‡ Journal of the Telegraph, Oct. 1 and 16; and Nov. 1, 1877. For similar observations see Telegraphic Journal, Mar. 1, 1788, p. 96; Journal of the Telegraph, Mar. 16, 1878, Dec. 1, 1877; The Electrician, vol. vi, pp. 207–303.

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These observations on inductive effects in telephone circuits began to be investigated; in 1877 Prof. E. Sacher of Vienna found that signals from three Smee cells sent through one wire 120 m. long could be distinctly heard in the telephone in another and parallel wire 20 m. distant.*

Prof. John Trowbridge of Harvard University was the first to systematically study the problem of electromagnetic induction signalling. His attention is concentrated chiefly on the use of interrupted or alternating currents at the transmitter and a telephonic receiver; in other respects his circuit was practically the same as Morse's (Fig. 3).†

In 1884 Trowbridge described another plan using a combination of both electromagnetic induction and earth conduction; later he discussed the phenomena of induction, electromagnetic and electrostatic, as distinguished from leakage or earth currents, and with reference to their employment in wireless telegraphy.‡

Experiments of Alexander Graham Bell

About 1882 Alexander Graham Bell made some successful experiments along this line suggested by Trowbridge. In his paper read before The American Association for the Advancement of Science, in 1884, he says:

"A few years ago I made a communication on the use of the telephone in tracing equipotential lines and surfaces. I will briefly give the chief points of my experiment, which was based on experiments made by Professor Adams of King's College, London. Professor Adams used a galvanometer instead of a telephone.

"In a vessel of water I placed a sheet of paper. At two

* Electrician, vol. i, p. 194.

† His investigations are discussed in detail in "The Earth as a Conductor of Electricity," Am. Acad. Arts and Sc., 1880; see also "Silliman's Am. Journ. Sc., 1880.

‡ Sc. Am. Supp., Feb. 21, 1891.

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points on that paper were fastened two ordinary sewing needles, which were also connected with an interrupter that interrupted the circuit about one hundred times a second.

"Then I had two needles connected with a telephone; one needle I fastened on the paper in the water, and the moment I placed the other needle in the water I heard a musical sound in the telephone. By moving this needle around in the water, I would strike a place where there would be no sound heard. This would be where the electric tension was the same as in the needle; and by experimenting in the water you could trace out with perfect ease an equipotential line around one of the poles in the water.

"It struck me afterwards that this method, which is true on the small, is also true on the large scale, and that it might afford a solution of a method of communicating electric signals between vessels at sea.

"I made some preliminary experiments in England, and succeeded in sending signals across the river Thames in this way. On one side were two metal plates placed at a distance from each other, and on the other two terminals connected with the telephone. A current was established in the telephone each time a current was established through the galvanic circuit on the opposite side, and if that current was rapidly interrupted you would get a musical tone.

"Urged by Professor Trowbridge, I made some experiments which are of very great value and suggestiveness. The first was made on the Potomac river. I had two boats. In one boat we had a Leclanche battery of six elements, and an interrupter for interrupting the current very rapidly. Over the bow of the boat we made water connection by a metallic plate, and behind the boat we trailed an insulated wire, with a float at the end carrying a metallic plate, so as to bring these two elements about one hundred feet apart. I then took another boat and sailed off. In this boat we had the same

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arrangement, but with a telephone in the circuit. In the first boat, which was moored, I kept a man making signals; and when my boat was near his I would hear those signals very well — a musical tone, something of this kind: tum, tum, tum. I then rowed my boat down the river, and at a distance of a mile and a quarter, which was the farthest I tried, I could still distinguish those signals.

"It is therefore perfectly practicable for steam vessels with dynamo machines to know of one another's presence in a fog when they come, say, within a couple of miles of one another, or, perhaps at a still greater distance. I tried the experiment a short time ago in salt water of about twenty fathoms in depth; I used then two sailing boats, and did not get so great a distance as on the Potomac. The distance, which we estimated by the eye, seemed to be about half a mile; but on the Potomac we took the distance accurately on the shore."

In 1886, convinced of the practicability of his method, Bell says further:

"Most of the passenger steamships have dynamo engines and are electrically lighted. Suppose, for instance, one of them should trail a wire a mile long, or any length, which is connected with the dynamo engine and electrically charged. The wire would practically have a ground connection by trailing in the water. Suppose you attach a telephone to the end on board. Then your dynamo or telephone end would be positive, and the other end of the wire trailing behind would be negative. All of the water about the ship will be positive within a circle whose radius is one-half the length of the wire. All of the water about the trailing end will be negative within a circle whose radius is the other half of the wire. If your wire is one mile long there is then a large area of water about the ship which is affected either positively or negatively by the dynamo engine and the electrically charged wire. It will be impossible for any ship

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or object to approach within the water so charged in relation to your ship without your telephone telling the whole story to the listening ear. Now if a ship coming in this area has a similar apparatus, the two vessels can communicate with each other by their telephones. If they are enveloped in fog, they can keep out of each other's way. The ship having the telephone can detect other ships in its track, and keep out of the way in a fog or storm. The matter is so simple that I hope our ocean steamships will experiment with it."*

This method of signalling, attempted later by Messrs. Rathenau, Rubens, and Strecker, was finally carried to a distance of nearly nine miles, but the advent of the work of Maxwell and Hertz followed by the practical application of their theories and discoveries by Marconi and others, proved such an advance in method, and the futility of trying to make earth conduction systems duplicate the records of the new Hertzian-wave telegraphy was so evident that work along that line was practically discontinued.

* Public Opinion, Jan. 31, 1886.

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CHAPTER IV

ELECTROSTATIC AND COMBINED INDUCTION-CONDUCTION TELEGRAPH SYSTEMS

Professor Dolbear's Electrostatic Telegraph

In 1882, at about the same time as A. G. Bell, Professor Dolbear of Tufts College, Boston, was also engaged on the problem of wireless telegraphy. His apparatus was somewhat more suggestive than any hitherto proposed and was awarded a United States patent in March, 1882. The following is an extract from his patent specification:

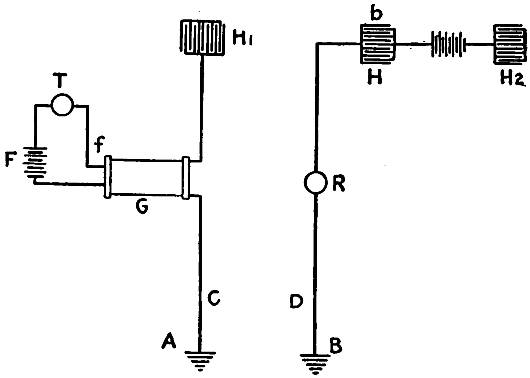

FIG. 4.

"In the diagram (Fig. 4), A represents one place and B a distant place. C is a wire leading into the ground at A, and D a wire leading into the ground at B; G is an induction coil having in the primary circuit a microphone transmitter, T, and a battery, F, which has a number of cells sufficient to establish in the wire C, which is connected with one terminal of the secondary coil, an electromotive force of, say,

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100 volts. The battery is so connected that it not only furnishes the current for the primary circuit, but also charges or electrifies the secondary coil and its terminals C, and H1.

"Now if words be spoken in proximity to transmitter T, the vibration of its diaphragm will disturb the electrical condition of the coil G, and thereby vary the potential of the ground at B, and the receiver will reproduce the words spoken in proximity to the transmitter, as if the wires CD were in contact, or connected by a third wire.

"There are various well-known ways of electrifying the wire C to a positive potential far in excess of 100 volts, and the wire D to a negative potential far in excess of 100 volts.

"In the diagram, H, H1, H2 represent condensers, the condenser H1 being properly charged to give the desired effect. The condensers H and H2 are not essential, but are of some benefit; nor is the condenser H1 essential when the secondary coil is otherwise charged. I prefer to charge all these condensers, as it is of prime importance to keep the grounds of wires C and D oppositely electrified, and while, as is obvious, this may be done by either the batteries or the condensers, I prefer to use both."

In the Scientific American Supplement, Dec. 11, 1886, Professor Dolbear gives some additional particulars:

"My first results were obtained with a large magneto electric machine with one terminal grounded through a Morse key, the other terminal out in free air and only a foot or two long; the receiver having one terminal grounded, the other held in the hand while the body was insulated, the distance between grounds being about sixty feet. Afterward much louder and better effects were obtained by using an induction coil having an automatic break and with a Morse key in the primary circuit, one terminal of the secondary grounded the other free in air, or in a condenser of considerable capacity, the latter having an air discharge of fine points at its opposite

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terminal. At times I have employed a gilt kite carrying a fine wire from the secondary coil. The discharges then are apparently nearly as strong as if there was an ordinary circuit.

"The idea is to cause a series of electrical discharges into the earth without discharging into the earth the other terminal of the battery or induction coil — a feat which I have been told so many many times was impossible, but which certainly can be done. An induction coil isn't amenable to Ohm's law always! Suppose at one place there be apparatus for discharging the positive pole of the induction coil into the ground, say, 100 times a second, then the ground will be raised to a certain potential 100 times a second. At another point let a similar apparatus discharge the negative pole 100 times a second; then between these two places there will be a greater difference of potential than in other directions, and a series of earth currents, 100 per second, will flow from one to the other. Any sensitive electrical device, a galvanometer or a telephone, will be disturbed at this latter station by these currents, and any intermittence of them, as can be brought about by a Morse key in the first place, will be seen or heard in the second place. The stronger the discharges that can be thus produced, the stronger will the earth currents be of course, and an insulated tin roof is an excellent terminal for such a purpose. I have generally used my static telephone in my experiments, though the magneto will answer.

"I am still at work on this method of communication, to perfect it. I shall soon know better its limits on both land and water than I do now. It is adapted to telegraphing between vessels at sea.

"Some very interesting results were obtained when the static receiver with one terminal was used. A person standing on the ground a distance from the discharging point could hear nothing; but very little standing on ordinary stones, as

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granite blocks or steps; but standing on asphalt concrete, the sounds were loud enough to hear with the telephone at some distance from the ear. By grounding one terminal of the induction coil to the gas or water pipes and leaving the other end free, telegraph signals can be heard in any part of a big building and its neighborhood without any connection whatever, provided the person be well insulated."

Explanation of Dolbear's System

Although Professor Dolbear's circuit arrangements resemble somewhat those of Marconi, his system lacked the essential features which, later, were applied so successfully, namely, electrical oscillations of high frequency at the transmitter and suitable detecting apparatus at the receiver.

Dolbear's results were clearly those of electrostatic induction and not, as he believed, due to conducting effects through the earth; the earth connections merely served to furnish one side of an electrostatic condenser, the other sides of which were supplied by the elevated conductors; the same results can be secured by using insulated metallic capacity areas, now known as counterpoises, instead of the earth as the lower halves of the radiating and receiving aerial systems. This is made plain by a study of the drawings taken from his patent specification.

The functions of the elevated condensers, H, H_1, and H_2, and of the battery b (Fig. 4), are not evident, since the underlying principle upon which the whole system is based does not explain their necessity. This principle is nothing more than a statement of the laws of electrostatic induction; it can best be understood by a study of the properties and action of the circuits with the unnecessary apparatus omitted. At the transmitter we then have a voice-controlled source of high potential, one end of which is earthed and the other connected to an insulated elevated conductor. At the receiver

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we have a similar elevated conductor earthed through an electrostatic telephone. When sound waves impinge on the microphone of the transmitter, fluctuating currents are set up in the primary of the induction coil; these produce fluctuating potentials at the terminals of the secondary winding, which are conducted to the elevated capacity area; the latter with the earth forms an electrostatic condenser with the intervening air as the dielectric. The electrostatic field of force of this condenser extends radially out and downwards from the aerial wire in curved lines, as is graphically shown in the accompanying diagram. (Fig. 5.) Now if an insulated body, such as the elevated wire of the receiver, lies within this field of force, potentials will be induced on it, the amplitude of which varies in unison with the variations of potential on the transmitting aerial wire.

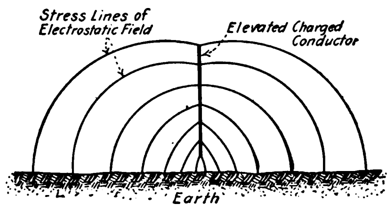

FIG. 5.

Since the earthed plate of the electrostatic telephone in the receiver remains constant at the earth's potential and since the other plate is connected to the elevated wire and subject to the inductive action of the transmitter, a varying difference of potential is therefore set up between the plates, with a consequent variation of attraction between them. One of the plates, which is a diaphragm of flexible metal or of some such material as thin sheet mica covered with a tin foil conducting area, is therefore made to vibrate and reproduce sounds produced at the transmitter.

Lowenstein's Electrostatic Telegraph

Mr. Fritz Lowenstein, a consulting and research engineer of New York, engaged in radio research work, suggested a

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similar method of signalling to short distances in 1912. This was based principally upon the marvellous sensitiveness of his potential operated receiving device. It could be used advantageously with the (magneto) telephone and was therefore adapted for both telegraphy and telephony; the telegraphic system, however, gave the best results for distance; telegraphic signals were sent, with his apparatus, from his laboratory at 115 Nassau Street to the Liberty Building at the corner of Nassau and Liberty streets, about a half mile distant. The transmitter consisted of a 20,000-volt transformer, the primary of which was energized by a 500-cycle alternating current. One terminal of the secondary was grounded to the water pipe system; the other was connected to a single, nearly vertical conductor (No. 8 stranded copper), the upper well-insulated end of which extended to a drop wire from the top of a three hundred-foot office building nearby.

The receiving station near the top of the Liberty Building consisted of a one hundred-foot length of bell wire suspended from a pole out one of the windows and connected to Mr. Lowenstein's ion controller detector,* the other terminal of which was grounded to the water pipes. The sensitive telephone connected to the instrument clearly indicated the Morse signals sent out at the transmitter. These were made by opening and closing the primary circuit of the transformer with a Morse key.

Passing over the work of Thomas A. Edison, W. F. Melruish, C. A. Stevenson, Professor Erich Rathenau, and others, we come to another serious attack on the problem of wireless telegraphy, which was executed in a masterly way by Sir William Preece, engineer-in-chief of the postal telegraph system in England.

* A potential-operated, ionized gas-detector and amplifier for radiotelegraphy, radiotelephony, and wire telephony.

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Preece's Induction-Conduction System

Preece's system was a combination of three previously existing systems, namely, earth conduction, electrostatic induction, and electromagnetic induction. Although it is certain that each of these three phenomena played a part in the transmission of the signals, their relative importance has not been definitely determined. A brief explanation will serve to make his method clear.

The signals were transmitted between two long, horizontal wires, one at the transmitter and one at the receiver. These

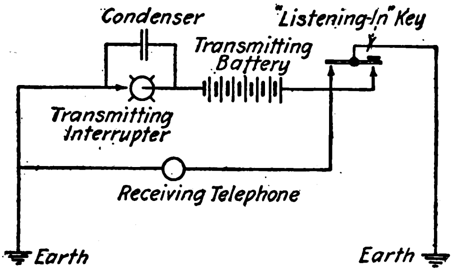

FIG. 6.

wires were supported parallel to one another on telegraph poles and were connected to earth plates of considerable area at their two ends. The diagram, Fig. 6, shows the connections at each station, which is a combined transmitter and receiver.*

The pulsating currents through the sending wire and the earth produce a variable electromagnetic and electrostatic field, which induces a fluctuating E.M.F. in the receiving circuit. This is indicated by sounds in the telephone. The induced currents are also augmented by the currents conducted through the earth itself.

* The use of a "breaking-in" key in this circuit will be found very interesting to practical operators since a number of inventors, within the last few years, have brought forward this principle as novel for use in radio systems.

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It has been shown that the hemispheroidal mass, represented by the lines of current-flow from one plate to the other, can be replaced electrically by a resultant conductor of definite form and position. This is illustrated in Fig. 7, where L is the line wire, PP the earthed plates, POP, PAP, etc., the equipotential lines of current-flow, and R the resultant conductor. The induction effects occurring between two such circuits are therefore the same as if they were composed entirely of metallic conductors of the same physical and electrical characteristics as the line wires with their resultant earth conductors. At Loch Ness, where the parallel wires were about three miles long, the calculated depth of the

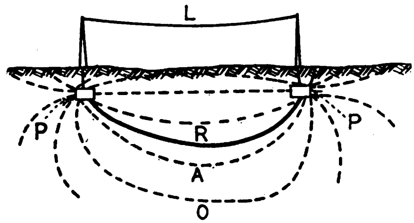

FIG. 7.

resultant earth conductor was about nine hundred feet. This arrangement of parallel line wires with earthed ends therefore gave all the advantages of signalling between huge, single-turn coils, with the increased effect due to earth conduction, and without the almost insuperable difficulties involved in constructing such coils above the earth.

In March, 1898, this system was permanently established for signalling between Lavernock Point, on the mainland, and Flat-Holm in the Bristol Channel, a distance of over three miles. Fifty Leclanche cells and an interrupter frequency of four hundred makes and breaks per second were used for transmitting, and a telephone served as the receiving indicator. The signals were very distinct, and it is said a speed of forty words a minute has been attained without difficulty.

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CHAPTER V

ELECTROMAGNETIC WAVE SYSTEMS

The profound speculations and mathematical researches of Maxwell on the electromagnetic nature of light, followed by the brilliant work of Hertz and his successors, are so familiar to the scientific public that a brief résumé of the evolution of the art is here sufficient.

Again we see that radio signalling, like most wonders of science, has not been an invention, in the popularly accepted meaning of the word, but rather a gradual, step-by-step development in which many prominent men of science have

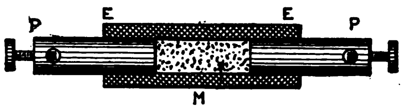

FIG. 8.

EE is the glass tube. P, P, the connectors, and M, the filings.

played a part. Maxwell's theories, published in 1865, laid the foundation, and Hertz, by a long and carefully executed series of experiments, paved the way; Hertz's successors, men who foresaw the practical value of these discoveries, utilized the material he laid bare for the production of a serviceable means of communication.

The greatest need in the extension of Hertz's work to greater distances, was a receiving wave detector of high sensitiveness. A crude form of such a detector had, as early as 1866 been used by S. A. Varley as a lightning arrester. In 1890 Prof. E. Branly of the Catholic University of Paris rediscovered the effects, already utilized by Varley, of Hertzian

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waves on the conductivity of metallic filings. He also observed the restoring or decohering effect of light tapping on the filings tube. In 1893 Sir Oliver Lodge repeated Hertz's experiments, using the "Branly tube," or "coherer," as he

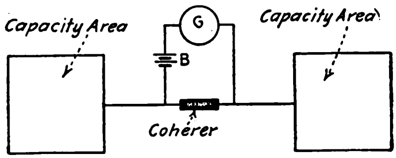

FIG. 9.

called it, in place of the micrometer spark gap in the Hertz resonator. Branly's coherer is shown in Fig. 8. Lodge's apparatus, connected for reception of signals, is shown diagrammatically in Fig. 9. With this apparatus he was able to observe Hertzian waves at distances up to about 150 feet.

Early Work of Nikola Tesla

Nikola Tesla, after completing the application of his discovery of the rotating magnetic field to electric motors in 1888, turned his attention to the problem of transmitting electrical energy to a distance without wires. His earliest plans were to transmit energy not only in small amounts, for purposes of communication, but also in amounts sufficient for industrial purposes.

The first public announcements of these plans were made in February and March, 1893. He delivered lectures before the Franklin Institute in Philadelphia, and the National Electric Light Association in St. Louis. However, in 1891, he had already described and shown, in a lecture before a scientific society, a method of lighting an electric lamp at a short distance without connecting wires. High-frequency oscillations were used in these experiments, but the power of the apparatus was small in comparison with that of his later lectures and experiments.

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In these lectures he expressed the conviction that: "It certainly is possible to produce some electrical disturbance sufficiently powerful to be perceptible by suitable instruments at any point on the earth's surface."

Describing his plan in detail he says:

"Assume that a source of alternating currents be connected as shown in the accompanying diagram (Fig. 10) with one of its terminals connected to earth (convenient to the water mains) and with the other to a body of large surface, *P*. When the electric oscillation is set up, there will be a movement of electricity in and out of *P*, and alternating currents will pass through the earth, converging to or diverging from the point *C*, where

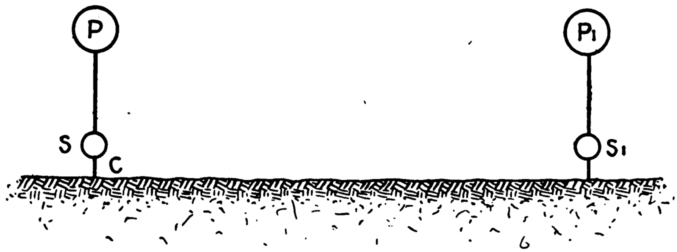

FIG. 10.

the ground connection is made. In this manner neighboring points on the earth's surface within a certain radius will be disturbed. But the disturbance will diminish with the distance, and the distance at which this effect will still be perceptible will depend on the quantity of electricity set in motion. Since the body *P* is insulated, in order to displace a considerable quantity the potential of the source must be excessive, since there would be limitations as to the surface of *P*. The conditions might be adjusted so that the generator or source, *S*, will set up the same electrical movement as though its circuit were closed. Thus it is certainly practicable to impress an electric vibration, at least of a certain low period, upon the earth. Theoretically it should not require a great amount of energy to produce a disturbance perceptible at great distance, or even

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all over the surface of the globe. Now, it is quite certain that at any point within a certain radius of the source, *S*, a properly adjusted self-induction and capacity device can be set in action by resonance. Not only can this be done, but another source S_1, similar to *S* or any number of such sources, may be set to work in synchronism with the latter, and the vibration thus intensified and spread over a large area; or a flow of electricity produced to or from the source S_1, if the same be of opposite phase to the source *S*. Proper apparatus must first be produced, by means of which the problem can be attacked, and I have devoted much thought to this subject."

Tesla continued his investigations along these lines and in 1898 had already developed apparatus of great power giving a pressure of four million volts and discharges extending through sixteen feet. At that time and even today this is considered remarkable. From 1899 to 1900 he continued his investigations and in 1900 he published, in the Century Magazine, a long article of absorbing interest and of great suggestiveness on "The Problem of Increasing Human Energy." Therein he described and illustrated with actual photographs his apparatus for producing pressures of over twelve million volts and capable of delivering energy at the rate of seventy-five thousand horse-power.

Professor Popoff's Receiver

Professor Popoff, in a communication to the Physico-Chemical Society of St. Petersburg, in 1895, described a form of receiving apparatus designed by him for the study of atmospheric electricity. His circuit arrangement which is shown in Fig. 11 is different from that of Lodge in that one terminal of the coherer is grounded, and the other is connected to a vertical conductor extending above the housetop. Here is introduced the well-known method of utilizing the electric signal bell for an automatic decoherer. Professor Popoff also

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used a form of tape recorder which automatically recorded the duration of the electrical disturbances in the atmosphere. This apparatus and circuit arrangement is precisely the same as that used by Marconi in his early experiments. That Popoff foresaw the possibilities of his receiver for Hertzian wave telegraphy is clearly evidenced by the concluding para-

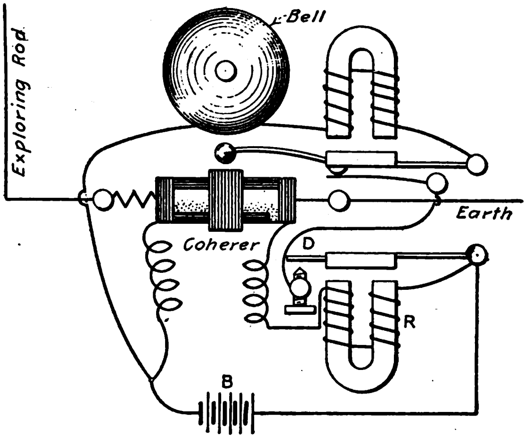

FIG. 11.

graph of a paper read before the Institute of Forestry of St. Petersburg. "In conclusion," he says, "I may express the hope that my apparatus, with further improvements, may be adapted to the transmission of signals to a distance by the aid of quick electric vibrations (high-frequency oscillations) as soon as a means of producing such vibrations possessing sufficient energy is found."

Marconi's Early Work

With Hertz's oscillator and Popoff's receiver Marconi began his experiments on his father's estate near Bologna, Italy, in 1895. Although only 22 years of age he had already acquired much knowledge of Hertzian waves, having studied under

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Professor Rosa of the Leghorn Technical School, and acquainted himself with the published writings of Professor Righi of the University of Bologna. After a year of experimenting Signor Marconi went to England and filed, in the Patent Office of Great Britain, an application for a patent, which was duly granted.

Later Improvements

Improvements in both the more efficient generation and reception of the electromagnetic waves have, since 1895, chiefly engaged the attention of radio investigators. Among the more important advances may be mentioned the introduction of the Tesla high-frequency transformer for coupled circuits by Lodge and Braun, instead of the direct spark-excited antenna of Marconi; the discovery and adoption of detectors suitable for use with the telephone; the introduction of alternating current and high spark frequencies for transmission; the utilization of Wien's discovery of the quenched spark gap; and the more recent attacks on the problem of selectivity. The recent work of Fessenden, Alexanderson, and Goldschmidt on the direct production of high-frequency alternating current of continuous amplitude for electric wave telegraphy and telephony, is worthy of mention.

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CHAPTER VI

POSSIBLE CONTROL METHODS FOR RADIO-DYNAMICS — SOUND WAVES

Every teledynamic system has two principal parts, namely, (1) the apparatus for the transmission and reception of the controlling energy, and (2) the apparatus or mechanisms to be controlled. This broad subdivision applies to such simple forms as the telegraph, where the energy-transmitting medium is a metallic conductor, and the receiver a relay controlling a sound-producing mechanism, as well as to the very complicated systems utilizing the ether as the connecting link.

Of these two divisions the first is to us by far the most important, if for no other reason because of the difficulty it has presented in the practical solution of such representative problems as torpedo control. It therefore demands careful consideration, especially with reference to a proper selection of the kind of radiant or other energy to be used.

The following table gives some of the most important forms of radiant energy in ether and air, their vibration frequencies, and detecting means capable of actuating mechanisms:

Waves	Frequency per sec.	Detector
Acoustic	16 to 35,000	Vibratory relay
Hertzian	50,000 to 2 billions	Hertzian wave detector
Infra-red, or heat	2 to 4000 "	Thermoelectric cells
Visible	4000 to 8000 "	Selenium cells
Ultra-violet	8000 to ? "	Trigger vacuum tube.

Besides these radiant energy means we may mention earth conduction, electrostatic induction, and electromagnetic induction.

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Choice of Control Energy

A number of important factors must be taken into consideration in order to make the best choice of these several control methods. Although the Hertzian wave system is employed in nearly all of the suggested applications of radiodynamics, and is to all appearances the most reliable and best, who can say that any one of these other possible methods, if it received the proper attention, would not be much simpler, and at the same time still more reliable?

Reliability is the factor of prime importance in the absolute and accurate control of a dangerous weapon like a torpedo, travelling, as it does, at a speed of between thirty and forty miles per hour and carrying large quantities of highly explosive material. Simplicity, freedom from accidental or intentional interference, and cost are other points which demand careful thought. The maximum range at which control is necessary, and indeed possible, is limited by vision. This, in clear weather, does not exceed eight miles, for even with a good binocular the torpedo cannot be seen beyond that distance. In cloudy or stormy weather the operations may be limited to two or three miles. This does not mean that the usefulness of the wirelessly directed torpedo is limited to calm, clear weather, for any attacking fleet or ship would be subject to the same conditions, inasmuch as the distance and accuracy of their fire is greatly affected by the condition of the sea and weather.

Difficulties to be Overcome

The reader may think of the four-thousand mile accomplishments of modern radiotelegraphy and immediately conclude that the problem of getting a sufficient amount of energy to the vessel is one of comparative simplicity. On the contrary this is one of the chief difficulties, and it has only lately begun to be surmounted.

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The following table will serve in a rough way to show the comparison between transmitted and received energies in various types of electrical energy-transmitting systems:

	Watts transmitted	Watts received	Ratio
Power line	10^6	10^6	1
Cable telegraph	1	10^{-3}	10^{-3}
Telephone	10^{-2}	10^{-6}	10^{-4}
Radiotelegraphy	10^5	10^{-8}	10^{-13}

From this table it may be seen that of the one hundred kilowatts used at a high-power radiotelegraphic transmitting station but one ten-trillionth part is received at a distance corresponding to the maximum working range, *i.e.*, the range at which the received power is measured in hundred-millionths of a watt. This range in daylight is usually in the neighborhood of three thousand miles, but is subject to considerable variation from day to day and from season to season; the night range is also very much greater than the day range during those parts of the year when atmospheric disturbances cause the least amount of interference.

In long-distance radiotelegraphic sets the transmitter is of such power (25 to 100 kw.), as would be excessive for torpedo control in coast defence. But far more important than this is the fact that the telephone, which is used as the receiving indicator in wireless telegraph sets, will give readable signals under an impressed e.m.f., of less than one-millionth of a volt, while to trip the most sensitive relay under ideal conditions requires about one-thousandth of a volt e.m.f. applied to its terminals. Under the conditions of shock and vibration aboard a small vessel in a rough sea the restoring spring of such an instrument must be set under sufficient tension to prevent the making of false contacts; the sensitiveness is thereby reduced to from one-fifth to one-tenth of its highest value. From these values we can readily see that a radiotelegraphic receiver may easily be as much as 5000 times as

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sensitive as the type necessary for the absolutely reliable control of mechanisms. Practically all systems of wireless signalling depend for their long-distance operation on this

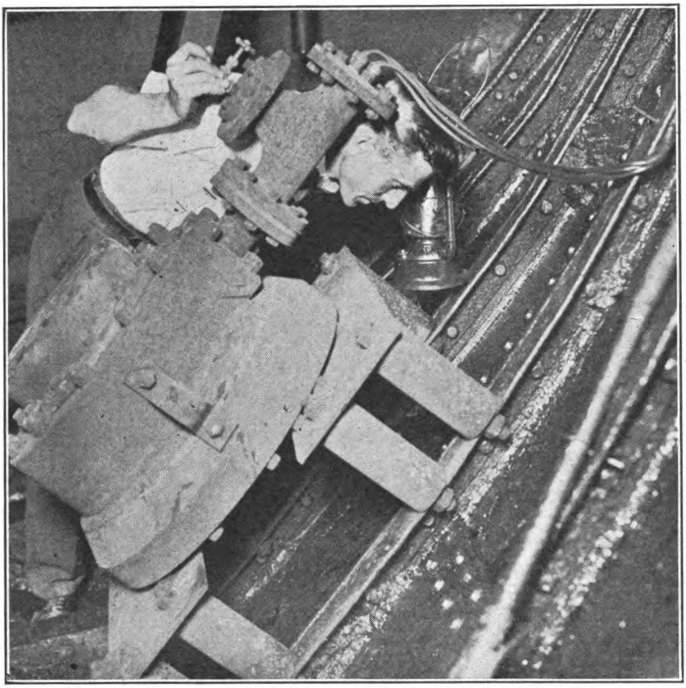

FIG. 12.
Prof. Fessenden's submarine sound signalling apparatus used to detect the presence of submarines. (*Published by permission.*)

extraordinary sensibility of the telephone; when used with a relay the distance over which they are operative likewise decreases tremendously.

Sound Waves in Radiodynamics

The employment of sound waves in air for radiodynamics has not been productive of any noteworthy results. Submarine

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signalling, however, has been developed to the point where the transmitting bell signals have been received at distances

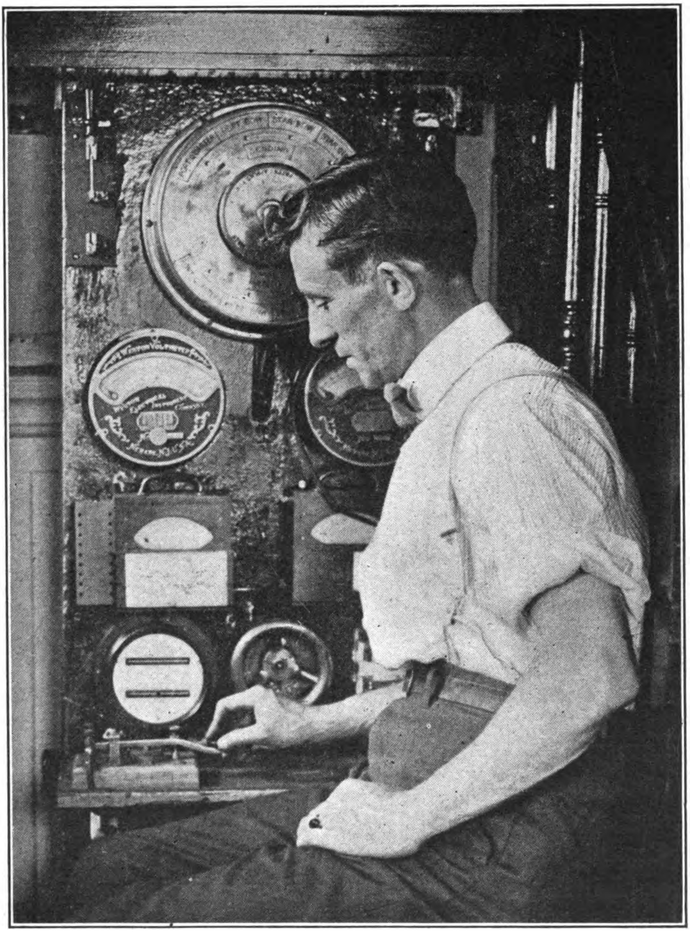

FIG. 13.
Operator sending submarine sound signals with the Fessenden apparatus.
(*Courtesy of the American Magazine.*)

up to about 25 miles. Prof. R. A. Fessenden, one of the pioneers and authorities on radiotelegraphy in the United

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States, signalled across Massachusetts Bay during the spring of 1914, with a submarine sound wave apparatus which he invented. Figs. 12, 13, 14 and 15 show Professor Fessenden and various parts of his submarine signalling system. These

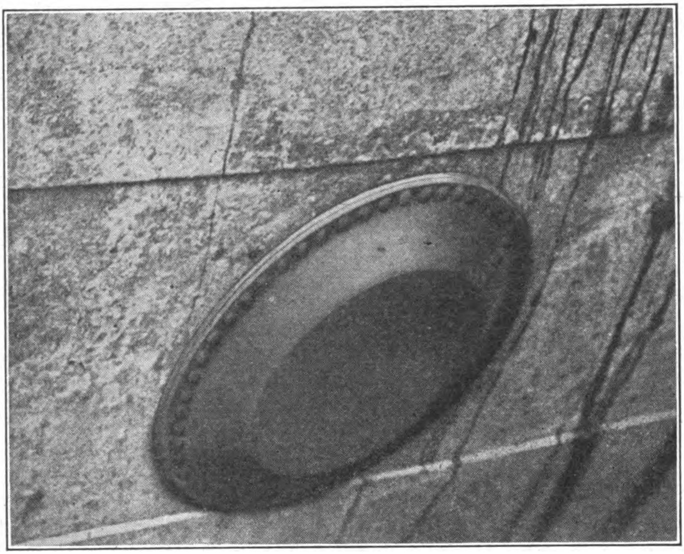

FIG. 14.
Vibrating steel diaphragm used as both transmitter and receiver in the Fessenden submarine signalling system. (*Courtesy of the American Magazine.*)

photographs are reproduced through the courtesy of the American Magazine.*

Although little has been done with this signalling system in adapting it to the severe requirements of torpedo control, its possibilities are not unworthy of consideration.

The fact that most steamships, war vessels, and submarine boats are now equipped with submarine signalling apparatus is ample proof of the practicability of this system for fog and

* For further details of submarine signalling apparatus see: Jour. Am. Soc. Nav. Engrs., Aug., 1914; Mar. Engr. and Nav. Archt., May, 1914; Proc. Am. Inst. Elec. Engrs., July, 1912.

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warning signalling. As practiced, a submerged bell, electrically operated, is used as the transmitter, while a submerged microphone transforms the received sound waves into electrical effects observable upon a telephone receiver; this receiving apparatus is in all respects the same in principle as the ordinary telephone which we have in our offices and

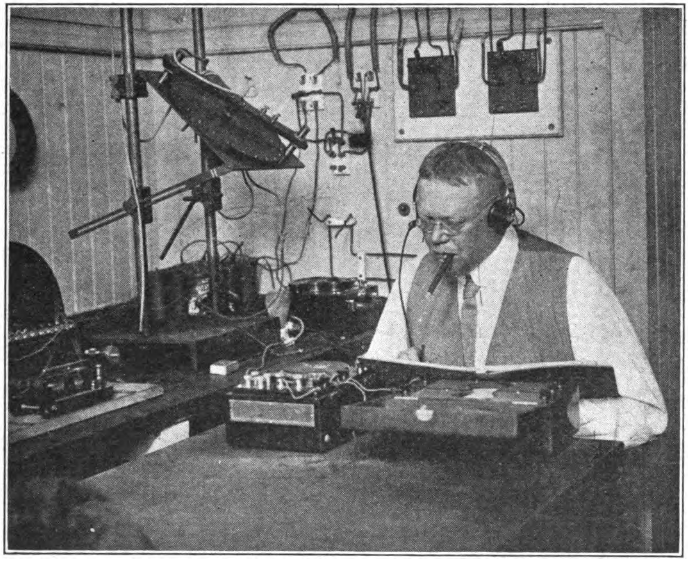

FIG. 15.
Professor Reginald A. Fessenden taking observations on the sound waves sent out by submarines. (*Courtesy of the American Magazine.*)

homes. An electric ear of this kind is usually installed on each side of the vessel, and two telephones provided in the pilot house for the observer. By switching from one to the other of these the general direction of the transmitter can usually be determined, since the receiving microphone on the side of the boat nearest the bell will give the stronger signal. When the signals are of equal strength in both telephones the direction of the bell at the dangerous reef can be determined

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by swinging the ship. The practicability of apparatus based on such an energy transfer method although not assured is not wholly uncertain. One advantage of no mean importance is that the torpedo could be entirely submerged, offering no target for the enemy's gun fire. Every other system except earth conduction in practice would require a portion of the receiving apparatus to project above the water.

By utilizing sound waves of frequencies below the audible limit (16 per second), the control impulses could not be detected by the enemy unless they were provided with special apparatus for that purpose. If such a transmitter be used with tuned mechanical elements in connection with current amplifying devices at the receiver, it is possible that an extremely simple and effective system of control could be developed.* The torpedo, although invisible, could be accurately located by means of two submerged microphones, which would respond to signals sent out by the torpedo itself. This scheme has been used in the European War to detect the presence of hostile submarine boats. The principal difficulties to be met in the use of submarine sound waves for torpedo control are the interfering signals, which the enemy might easily send out, and the very weak electrical effects produced by the transmitter at battle-range distances. The former is an extremely difficult problem. The latter might be overcome by using a simple form of amplifier, such as De Forest's.

* Such a scheme was described by the author in a lecture on The Wirelessly Directed Torpedo, before the Indianapolis-Lafayette section of the American Institute of Electrical Engineers in October, 1913.

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CHAPTER VII

INFRA-RED OR HEAT WAVES

Omitting Hertzian waves for the present we come to the infra-red rays as a possible means of effecting mechanism operation at a distance. The great sensitiveness of the bolometer, thermo-pile, and other thermal and thermo-electric detectors suggests the use of these rays as a form of wave energy capable of serving our needs.

No mention of the use of radiant heat for operating distant switches has been found in scientific literature. As a means of telephoning to short distances, however, it was among the first to be suggested, as previously stated.

Stimulated by the accounts of the extreme sensitivity of radiant heat detectors and of their use in the measurement of stellar radiations, the writer has given some thought to the possibility of using heat waves as a control agency in a system for the wireless direction of torpedoes.

Let us consider first the general advantages and disadvantages of such a control energy, assuming that we have generating means of such power and receiving detectors of such sensitiveness that we are able to control switches at useful distances.

One of the first advantages, and perhaps the greatest, lies in our ability to *direct* this energy at will. By means of the highly-polished, parabolic surfaces of such metals as silver and zinc, we can direct practically the whole of our generated energy into a beam of parallel rays. Surfaces of silver and zinc, when well polished, will absorb no more than two or three

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per cent of the incident radiant energy, the remaining ninety-eight or ninety-seven per cent being reflected.

In order to secure the advantages of direction by the use of parabolic reflectors, we must confine our source of heat to a comparatively small area. But if the area be small the rate at which the energy is radiated per unit of area must be correspondingly large. A high radiation rate per unit of area can only be obtained with a high temperature. In order then that we may be able efficiently to utilize heat radiations we must have first, a source of easily controlled energy which can readily be converted into the energy of radiant heat; second, a means of developing an extremely high emission rate per unit area; third, a means of limiting the radiation to a small area; and fourth, a properly shaped reflecting surface of material suitable for directing the heat energy developed into a beam of parallel rays. Disregarding our primary assumption, we must in addition be able to project these rays upon a swiftly moving receptor at five miles distance with sufficient effect to produce definite, mechanical movements at will.

These requirements are admirably met in our present high-power searchlights. Electricity as a prime source of energy lends itself easily to our needs because of its extreme flexibility; the electric arc as a means of transforming this energy into heat is not only extremely efficient, but fulfills the requirements of small area and very high temperature as well. The energy in the visible portion of the electric arc spectrum does not exceed ten per cent of the input energy; but with this we are not particularly concerned, since a "black body" receiving surface will enable us to convert practically all of the radiation incident upon it, including, besides all of the infra-red, the visible, and most of the ultra-violet also.

The energy emission rate per unit of area, which is a function of the energy density per unit of crater surface, is exceedingly high; the energy density may reach twenty-one

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and one half watts per square millimeter, and the temperature may rise to the vicinity of three thousand eight hundred degrees Centigrade. Moreover the energy of the high-temperature portion is limited to a comparatively small value by the low coefficient of thermal conductivity of the electrode material. This allows a sufficiently close approach to the "point source" ideal desired with parabolic reflectors, for practical utility.

Electric searchlights, or "projectors," as they are frequently called, have been built with parabolic reflecting mirrors sixty inches in diameter. Such a projector of the type used in the United States Navy is shown in Fig. 16. The power of these projectors can easily be raised to fifteen or twenty kilowatts. Were it necessary, heat-wave generators of this kind could be constructed having a capacity for transforming an electrical energy of one hundred kilowatts into the energy of radiant heat. The infra-red radiations of the electric arc may be increased by the addition of barium chloride to the arc electrodes.

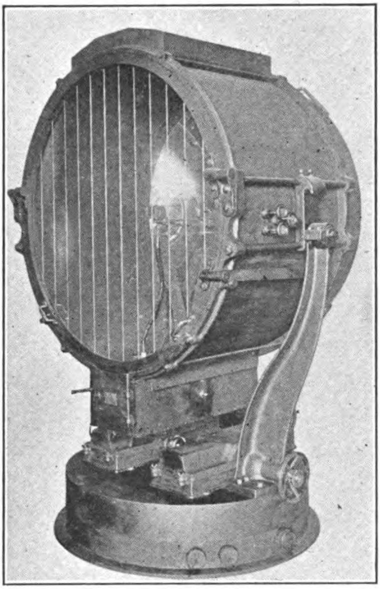

FIG. 16.
Sixty-inch projector used with radio-dynamic torpedoes. (*Published by permission of General Electric Co.*)

Invisibility

A searchlight transmitter can be installed directly on a harbor or coast line and so masked as to be completely in-

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visible to ships several miles at sea. The electric power would preferably be generated at a central power plant and transmitted over a hidden high-tension transmission line to a number of these hidden control stations. By means of step-down transformers (and rotary-converters if it is necessary to use direct-current arcs), the high tension line currents furnished by the central station would be transformed to currents of proper potential and power for the operation of the high-power, electric-arc, heat-wave generators.

Control operators at each hidden transmitter would be in constant communication with each other and with the military head of the harbor defenses in order that the control operations might be constantly in the hands of the operator in the most advantageous position with respect to the attacking war vessels.

Selective Operation

Since heat waves as a control agency, unlike Hertzian waves, sound waves, electromagnetic and electrostatic induction, or earth conduction, can be directed at will, their use demands no consideration of the selectivity problem, the solution of which has ever been practically unattainable under the conditions imposed in torpedo control. Although it is possible to produce Hertzian waves with fronts perpendicular to the direction of propagation, the difficulties involved in constructing reflectors of sufficient size for the wave-lengths necessary are very great from a practical point of view. Other means have been developed for directing Hertzian waves, among which may be mentioned the radio-goniometer of Bellini and Tosi, but in practice it has been found that the power of such transmitters is limited.

In order to prevent the enemy from projecting the beams of their own searchlights onto the receiver of our torpedo, the latter is provided with a gyroscope which serves to keep the receiving heat detector always facing toward our own trans-

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mitters on shore and away from the enemy at sea, a screen of opaque material on the side toward the sea providing means of intercepting the rays from the enemy's lights. This same gyroscope at night serves to keep from the view of the enemy at sea, the screened signal lights on the torpedo, which at all times are plainly visible from shore, and which are automatically operated by the control apparatus within the torpedo. Their purpose is to permit the control operator on shore to follow the direction of the torpedo without keeping his transmitting searchlight directed upon it, and thus in continuous view of the attacking ships, and at the same time automatically to signal back the operations occurring on the torpedo.

The rays of the searchlight are invisible in bright daylight unless an observer be directly in their path; this is desirable, inasmuch as it prevents the enemy from locating the screened control stations. At night the powerful light is a distinct advantage in locating any attacking ships, and, when necessary, in following the torpedo itself. Should it become necessary to have the control station invisible during the night as well as by day, suitable ray filters would be necessary. Substances which will screen off or absorb the visible radiations and allow the longer infra-red waves to be transmitted, that is, substances which are said to be "diathermanous," are: black fluorite, smoky quartz, black glass, and a strong solution of iodine in carbon disulphide; gases not near the point of condensation are also highly diathermanous.

Dispersion and Atmospheric Absorption

The best of our present-day searchlights are not capable of producing strictly parallel rays. The non-parallelism usually amounts to at least three or four degrees. Because of this dispersion the beam of a searchlight which at the mirror is sixty inches in diameter, may be five hundred or a thousand feet in diameter at a distance of five miles. It is obvious,

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therefore, that the illumination intensity directly in front of the searchlight will bear to the illumination intensity at five miles a ratio equal to the ratio of the respective areas of the beam at these points; this equals the ratio of the squares of the radii of the beam at these points. In the case of the sixty-inch searchlight, assuming that at five miles the beam has a diameter of one thousand feet, this ratio would roughly equal twenty-five thousand to one. It is possible, however, that the dispersion could be reduced by a more careful attention to this useless waste of energy. No necessity has yet arisen for such a reduction in searchlights as now used, since it is desirable to illuminate the entire length of modern, five-hundred-foot battleships at such distances.

Atmospheric Absorption

Some of the energy of the rays is absorbed in the atmosphere. If the vibrating rates of the atmospheric gases are equal to any of the vibration rates in the projected waves, part of the energy of those particular waves will be absorbed. In this connection it may be possible so to choose the electrode materials for the arc that vibration rates produced in the arc will not be equal to those of the atmospheric gases, thereby evading the energy losses due to this cause.

In foggy or rainy weather the atmospheric absorption would be materially increased because water is not very diathermanous. It is also true, however, that in such weather battle ranges are materially decreased because of the decrease in the limit of vision, which, in turn, is brought about by mist, rain, or fog. It is difficult to foretell whether or not the two would decrease at the same rate.

Receiving Radiant Heat Detectors

The development of sensitive radiant heat detectors has followed several distinct lines corresponding to the varying

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phenomena of radiant energy in the form of heat waves whose lengths are longer than 0.77 μ. The length of the visible waves lies between 0.77 μ and 0.39 μ, those above 0.39 μ being in the ultra-violet.

Those effects of radiant heat which have been used in the production of sensitive detecting instruments may arbitrarily be classified as follows:

1 Volumetric expansion (chiefly of gases).
2. Thermoelectric currents.
3. Resistance change in electrical conductors.
4. Stresses in rarefied gases.
5. Linear expansion of solids.

As an example of the first may be mentioned the micro-radiometer of Weber.* This instrument is a combination of a differential air thermometer and a Wheatstone bridge. A thin glass tube which contains at its center a drop of mercury surrounded on both sides by a solution of zinc sulphate, constitutes two arms of the bridge. Platinum electrodes sealed in the bulbs at each end of the tube dip into the zinc sulphate solution. One of the bulbs, which is made of an opaque non-conducting material, and coated inside with lampblack, is fitted with a fluorite window. When radiant energy enters through the non-absorbing, fluorite window it is absorbed by the contained gas and by the lampblack. Thus heated, the gas expands and pushes the liquid toward the opposite bulb. This changes the relative lengths of the mercury column and of the solution between the platinum terminals; the balance of the bridge being upset, a deflection of the galvanometer consequently occurs. This instrument was stated to be sensitive to a temperature change of one millionth of one degree.

* Weber, Archiv. Sci. phys. et Nat. (3) 18, p. 347; 1887.

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Thermoelectric Detectors

These radiant heat detectors may be divided into two groups, namely, those in which the detector and the sensitive galvanometer with which it is used are two separate and distinct instruments, and those in which the two are combined into a single instrument. The thermopile is representative of the first group, and for the second we have the radiomicrometer.

Let us first consider the thermopile. From the very beginning of radiant energy measurements, the power of this form of wave energy in the ether for developing electric currents in circuits containing junctions of dissimilar metals, has found wide application. Tyndall, Rubens, and other pioneers in this domain secured very satisfactory results with the thermopile, in spite of its great heat capacity. Rubens has described* a linear thermopile consisting of twenty junctions of iron and constantin wires about 0.1 mm. to 9.15 mm. in diameter (resistance 3.5 ohms). When used with a galvanometer having a figure of merit of $i = 1.4 \times 10^{-10}$ amperes (resistance = 3 ohms, period = 14 seconds), a deflection of one scale division indicated a temperature change of $1^\circ.1 \times 10^{-6}$. A candle at five meters gave a deflection of 10 cm. or 250 cm. at one meter. The area of the exposed face of the pile is about 1.6 $\overline{\text{cm.}}^2$. The heat capacity was such that its stationary temperature was reached in less than seven seconds.

If p = the thermoelectric power in microvolts per degree ($= 53 \times 10^{-6}$ volts for iron and constantin), n = the number of junctions exposed, and r = the internal resistance, of the thermopile; and if we combine the pile with a galvanometer, which, with an internal resistance of w ohms, gives a deflection of m millimeters per microampere, then a deflection of 1 mm.

* Rubens, Zs. fur Instrumentenkunde, 18, p. 65; 1898.

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indicates a change in temperature at the junctions of Δt degrees when

$$\Delta t = \frac{r + w}{npm}.$$

The highest efficiency is obtained when the resistance of the thermocouple is equal to the combined resistance of the connecting wires and of the auxiliary galvanometer.

Coblentz has described* a linear thermopile of bismuth-silver junctions which had a heat capacity low enough to attain ninety-two per cent of its maximum temperature in two seconds. It has a completely opaque surface, this novelty being secured by a series of overlapping receivers; it has a high sensitivity; the materials are sufficiently strong to withstand rough usage; it is quick acting, and yet sufficiently massive to permit operation in the open without being disturbed by the cooling effect of air currents.

The efficiency of the thermocouple is such that one microwatt of radiant power produces about 0.02 microvolt per thermojunction in the thermopiles of bismuth-silver, or in larger units 1 watt = 0.02 volt.

At present we have no exact knowledge of the mechanical equivalent of the radiations of large searchlights, but for sunlight we have accurate data. Upon the reasonable assumption that we can develop searchlights which, with the aid of collecting and concentrating means at the receiver, will produce received effects at five miles equal to those produced by sunlight without such concentrating means, we may proceed to make calculations on a sunlight-source basis. Mr. W. W. Coblentz has kindly made for the author the following calculations on the current developed in a thermocouple with sunlight as a source:

* Various Modifications of Bismuth-Silver Thermopiles Having a Continuous Absorbing Surface, Scientific Papers of the Bureau of Standards, No. 229, p. 132

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The solar radiations reaching the earth's surface are about 1.0 to 1.2 gr. cal. $\overline{cm.}^2$ per minute = $\frac{1}{60}$ gr. cal. $\overline{cm.}^2$ sec.$^{-1}$, or about $\frac{1}{15}$ watt per cm.^{2} per second. For a quick-acting thermopile the receiver has an area of about 0.04 $\overline{cm.}^2$, so that when exposed to sunlight the amount of radiant power intercepted is

$$\frac{0.04}{15} = 0.003 \text{ watt.}$$

This would produce 0.016 $\times$ 0.003 = 48 $\times$ 10^{-6} volt, or a rise in temperature of about one-half degree centigrade.

By increasing the number of couples to 100 and placing the whole in vacuo, the sensitivity could be increased 200 times. The e.m.f. developed would then be 200 $\times$ 48 $\times$ 10^{-6}, or very nearly 0.01 volt. Within recent years relays have been perfected which will operate with impressed voltages of approximately 0.003 volt. A factor of safety is therefore, apparent, since the received current is three times that required for operation. These rough calculations indicate that heat-wave control systems are quite within the range of possibility.

Our calculations are based on the assumption that we can produce, at five miles, thermoelectric effects equal in magnitude to the effects produced at the earth's surface by the solar radiations. It is probable that this assumption can be realized in practice. Even if this were not possible, we have means of increasing the received effects so that a much smaller heat intensity at the receiver would produce the desired results. The De Forest three-stage amplifier is capable of amplifying minute received currents to from five hundred to a thousand times their original strength. These amplifiers operate best with pulsating or alternating received currents. It would be a simple matter to use a current interrupter of either the motor-driven or vibrating-buzzer type for breaking up the direct current produced in the thermopile. This would intro-

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duce some complications. The thermopile and galvanometer relay, with an auxiliary relay capable of handling larger currents would, however, form a very simple and reliable receiver.

Radiomicrometers, Bolometers, and Radiometers

Three other well-known types of radiation detectors are the radiomicrometer, the bolometer, and the radiometer. The radiomicrometer, which was invented independently by d'Arsonval and Boys, consists essentially of a moving-coil galvanometer of a single-loop with a thermo-junction at one of its ends. It is, as previously stated, a combined thermocouple and galvanometer.

The bolometer is simply a Wheatstone bridge, two arms of which are made of very thin, blackened, metal strips of high electrical resistance and high temperature coefficient, one or both of which are exposed to radiation.

The radiomicrometer, because of its great delicacy, is not so suitable for radiodynamics as the separate thermopiles and galvanometer relays. The bolometer is an extremely sensitive radiation detector, but careful precautions must be observed in keeping at a constant temperature the air in which it is contained so as to avoid the drifting of the zero position of the auxiliary galvanometer.

The radiometer of Crookes, a scientific toy which may be seen in many jeweller's windows, has been modified for radiant energy measurement. Nichols* has described a radiometer consisting of two blackened vanes of platinum attached to a horizontal arm and suspended in a vacuum by a quartz fiber. Although instruments of this type will detect a change in temperature of one one-millionth of one degree, their extreme delicacy and sluggishness make them less suitable than thermopiles for radiodynamics.

* Phys. Rev., 4, p. 297; 1897.

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The Tasimeter

Edison's tasimeter consists essentially of a vulcanite rod and a microphonic contact. The vulcanite rod, which has a high coefficient of linear expansion, is made to exert a pressure on the microphonic contact by means of a screw press. A slight expansion of the rod, brought about by a slight increase in temperature, causes a change in pressure on the microphonic contact, and consequently a change in its resistance. When the microphone forms one arm of a Wheatstone bridge the apparatus becomes a very sensitive radiation detector.

Edison used a solid rod of hard rubber in compression against two blocks of carbon, as shown in Fig. 17. Owing to

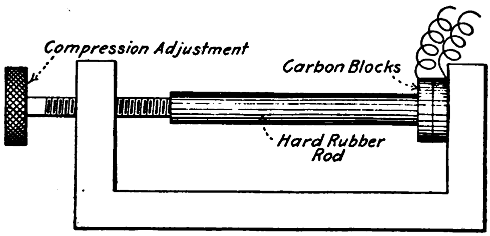

FIG. 17.
Simple form of Edison's tasimeter.

the large mass of rubber in the rod and to the low coefficient of conductivity of hard rubber, this form is sluggish in its action.

The author has modified this instrument in order to increase its sensitiveness and to decrease the period required to attain its maximum temperature under the action of a given intensity of received radiation. The modification consists substantially in substituting a sensitive telephone microphone of the carbon granule type for the blocks of carbon, and in replacing the hard-rubber rod with a thin strip of hard rubber. This strip is maintained in tension by an adjustable spring. The arrangement of microphone, hard-rubber strip, and adjusting screws is shown in Fig. 18.

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This instrument, when connected in circuit with a battery and ammeter, will readily indicate a change in current sufficient to operate a relay, if influenced by the heat of a bunsen burner at a distance of one meter. Although not lacking in sensitiveness, heat detectors of this type are subject to vibration, jars, and sounds; a weakness which disqualifies them for radiodynamics, particularly in the radiodynamics of torpedo control.

Thermostats

In an endeavor to provide a sensitive, quick-acting, heat-detecting instrument which will close a circuit directly without

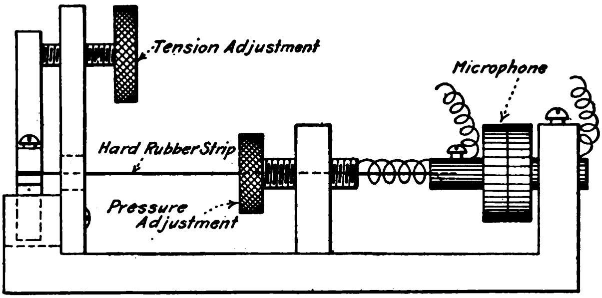

FIG. 18.

the aid of a sensitive relay, the author has experimented with various types of thermostats. After experimenting with mercury-in-glass thermostats designed especially for quick action, with composite-strip thermostats of both the straight and spiral types, and with alcohol, mercury, and gas thermometers, the conclusion was reached that a modification of the differential gas thermometer would be far more suitable than the other types, because of its high sensitiveness and rapidity of action.

The most satisfactory form thus far produced is shown in Fig. 19. The general scheme of this type of instrument was suggested to the author by Prof. E. S. Ferry, of Purdue

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University. In the drawing A is the heat absorber of thin, lampblacked platinum, B and D, two glass gas-chambers, connected by a glass tube of small bore; B is lampblacked inside. M is a thread of mercury; $W–W$ are water or alcohol columns whose function is to prevent the mercury from moving by jumps under the action of the expanding gas in B; and $C–C$ are contact wires of platinum sealed into the glass tube so as to make contact with the mercury thread.

If heat rays fall upon the platinum disc A, they are absorbed and their energy appears as a rise in the temperature of A.

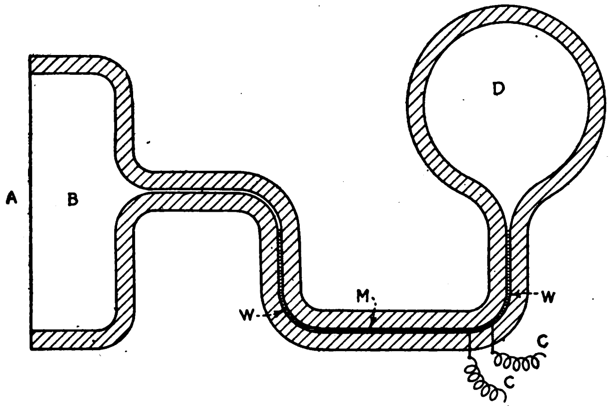

FIG. 19.

A has a very small heat capacity because of its low specific heat and its thinness, and it therefore requires but a small amount of heat energy to raise its temperature. Since platinum has a high coefficient of thermal conductivity, the heat is rapidly conducted to the gas in the closed chamber B. This chamber is so designed that the distance from the platinum to any part of the enclosed gas is small, in order that the conduction-time-lag through the gas may be a minimum. The inside of B is lampblacked in order to prevent escape of heat by radiation through its walls. The temperature of the

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enclosed gas therefore rises rapidly to the temperature of the absorber. This gas, which is especially chosen for its maximum coefficient of volumetric expansion and its minimum specific heat, expands and pushes back the liquids in the tube. The mercury *M* will then short-circuit the two connecting wires *C–C*, thus closing the external circuit. If the source of heat be removed the order of actions is reversed. The absorber *A* then becomes a rapid and efficient radiator, and the heat of the gas in *B* is dissipated through conduction to and radiation from the platinum disc *A*. Any change in normal temperature, *i.e.*, the temperature of the air in which both *A* and *D* are contained, will not cause any appreciable change in position of the mercury thread because pressures will be produced in the two gas chambers which are equal and opposite.

W–W consist of some non-conducting liquid of low specific gravity. Without some such steadying means the mercury thread will have a tendency to move in jumps. The specific gravity should be low in order that a slight difference in the levels of the two columns will not require a great difference in pressure between *A* and *D*. If mercury were used a relatively large difference in pressure between *A* and *D* would be necessary in order to produce a motion of *M* sufficient to bridge contact wires just above the normal position of the mercury surface.

The author has constructed thermostats of this type which will operate satisfactorily in strong sunlight, an exposure of from one to five seconds being sufficient to produce the maximum deflection of the mercury thread. The complete periods were considerably less than twice these values.

These results can probably be improved upon. The author has experimented with gases containing vapors of alcohol, ether, carbon tetrachloride, and similar liquids whose saturated vapors have a high coefficient of volumetric expansion. The results of these experiments are promising.

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A differential gas thermostat of this type, if developed to the proper sensitiveness, would be as near the ideal of a heat-wave receiver as we can hope to reach. Its extreme simplicity and ruggedness, and the absence of the usual sensitive relay are its chief advantages; all other types of receiving apparatus, whatever the nature of the control energy, require, besides various other apparatus, a sensitive relay, usually of the galvanometer type; this, in turn, requires a more rugged relay for handling the electrical energy used in performing the various operations aboard torpedoes.

Heat-wave control systems, we may therefore state, are not only within the range of possibility but of probability as well. The extreme simplicity and ruggedness of both transmitter and receiver, the absence of masts and other aerial targets, the satisfactory solution of the interference problem, the near approach to complete invisibility of both transmitter and torpedo, and the almost indiscernible form of the control energy are factors that commend heat waves as a connecting link between the shore and the wirelessly directed torpedo.

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CHAPTER VIII

VISIBLE AND ULTRA-VIOLET WAVES

As shown by the table, the visible waves vary in frequency from 8000 billions down to 4000 billions per second, representing the various colors from violet, down through blue, green, and yellow to red, and including all the thousands of intermediate shades. Quite apart from the various optical and chemical effects these waves are capable of producing, their chief interest to us lies in their ability to effect changes in the electrical characteristics of various substances. These changes can be utilized for the operation of delicate indicating or relaying instruments. Selenium, described more fully in a subsequent chapter, is the most important of these substances affected by light. Systems of telegraphy and telephony based on its peculiar property of changing its electrical resistance under the influence of light, have occupied the attention of numerous scientific men since Willoughby Smith's discovery of that property in 1875. But no account of its application to torpedo control can be found. The writer ventures here to present some experimental data and observations made by him, especially in view of the possible adoption of a light-wave selenium control system for the Hammond dirigible torpedo.

From a number of selenium cells of varying types and resistances two, made by Dr. Korn of Vienna, were chosen. The sunlight and dark resistances of one of these were 2000 and 5200 ohms respectively; of the other, 1300 and 3000 ohms. These two cells were to be used in selective light telegraphy tests and it was decided first to learn the applied e.m.f.

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range in which the cells operated with the greatest sensitiveness and smallest inertia. The 2000–5200 ohm cell was first tried. It was connected in a series circuit with a battery and microammeter, and with a potentiometer for accurate regulation of potentials. The operation was much better with

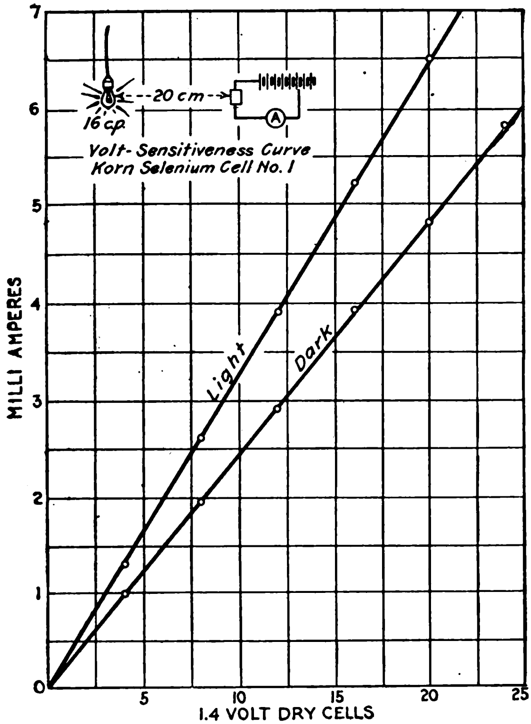

FIG. 20.

the highest current density permissible with the microammeter, so it was decided to use a milliammeter and higher potentials. Potentials as high as 25 volts were used and the results are given in the curve of Fig. 20. This shows graphically the relation between applied voltage, current, resistance, and the current change between light and darkness.

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The current change is the factor of principal importance. It is noted that this value increases directly as the voltage, and that the highest value corresponds to the highest value of current density permissible. It was learned that if this exceeded five or six milliamperes for an hour or more, the cell would get out of order, and a telephone inserted in the circuit indicated that the current was varying at a rate of several thousand per second. The sound was an irregular hissing or frying noise, resembling closely the sounds in a radio receiver due to heavy atmospherics, or that heard in an ordinary telephone during the progress of a thunder storm in the immediate vicinity. The tests were made with a 16-c.p. carbon filament electric light, at a distance of 50 cm.

The 1300–3000 ohm cell, which we shall designate No. 2, was given a similar test under slightly different conditions. The 16-c.p. light was placed at a distance of 10 feet, and a five-inch condensing lens was used to increase the intensity of illumination on the active surface of the cell. The curves of Fig. 21 show the relation between the e.m.f., current, resistance, and current change with the No. 2 cell.

By a comparison of Figs. 20 and 21, it is readily observed that the combination of the No. 2 cell with the condensing lens was more sensitive at a distance of 10 feet than the No. 1 cell at about 20 inches. The indications of the milliammeter showed that when the cells were brought from darkness to light the resistance dropped very quickly to about two-thirds the resistance change value, and then to the lowest value in about five or ten seconds. From this observation it is obvious that the cell would operate much more efficiently for slow variations in the light intensity than for rapid, such as are used in light telephony, since the lagging part of the current change represented by the change occurring, say one-fiftieth of a second, after a given change in illumination, would be of no value where the variation frequency

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exceeded 50 per second. It would seem, therefore, that the higher characteristics of the human voice, which may reach vibration rates of five thousand per second, would be reproduced with less distinctness than the lower characteristics. This is actually the case with light telephony as well as with

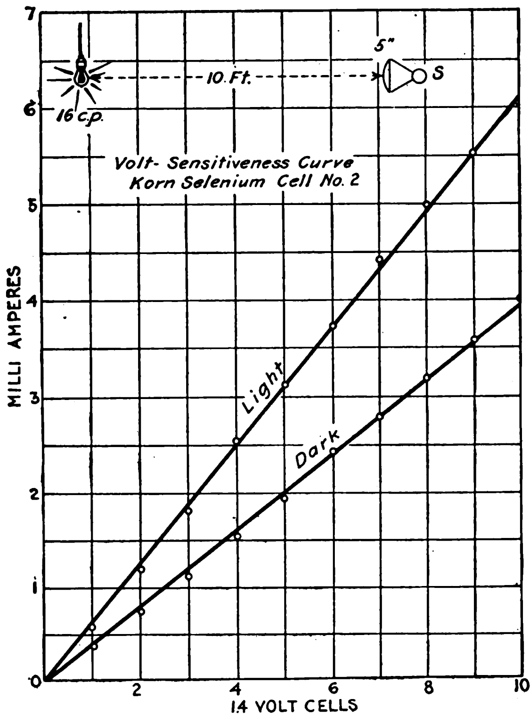

FIG. 21.

wire telephony, the inertia being too great to permit the resistance to follow the rapid variations in the light's intensity; in wire telephony, however, the inertia is mechanical rather than electrical, except in very long distance lines where the capacity comes into play. It was also found that the cells were more sensitive in some parts of the active surface

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than in others. The five-inch condensing lens was used to furnish a small spot of intense light with which to explore the surface of the cell. When the diameter of this spot was made about one-sixteenth of an inch the best results were secured. The surface of the selenium, to secure this condition, was placed very near the focal point of the lens. The sensitive spots could then be accurately located, and in some places the cell was several times as sensitive as in others. Experimental investigations of the cause of this spot sensitiveness were not made.

A test was made with the No. 2 cell with a view to determine the possible value of a selective light signalling and radiodynamic control system devised by the writer. In these tests a light interrupter was used to effect the periodic illumination and darkening of the selenium cell at rates up to 300 per second.*

Fig. 22 illustrates the general arrangement of the apparatus as well as the results of the test. The light used was a 4-c.p. carbon filament electric lamp, and the interrupter was, as shown, similar to those used on motion picture machines; it, however, had a much larger number of blades, and, as shown in the sketch, was attached to the shaft of a fan motor. A rheostat and tachometer permitted variation and exact knowledge of the speed, so that any desired interruption frequency could be obtained.

At the receiver a three-inch condensing lens was used with the selenium cell. The latter was connected in circuit with a variable battery, a milliammeter, and the primary of a ferric transformer. The secondary of the transformer was connected in a series oscillatory circuit with another lumped inductance and variable capacity of the Korda type. By varying the capacity or inductance of this circuit, it could be

* In later tests an arc light supplied with alternating current of from 60 to 600 cycles was used to furnish the periodically fluctuating light.

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brought into resonance with the periodicity of the light interruptions. The oscillatory currents set up in this circuit by the action of the pulsating currents in the selenium cell circuit, when the two were in resonant operation, were less than one ten-millionth of an ampere. Since that value did not give a satisfactory telephone signal, an amplifying device,

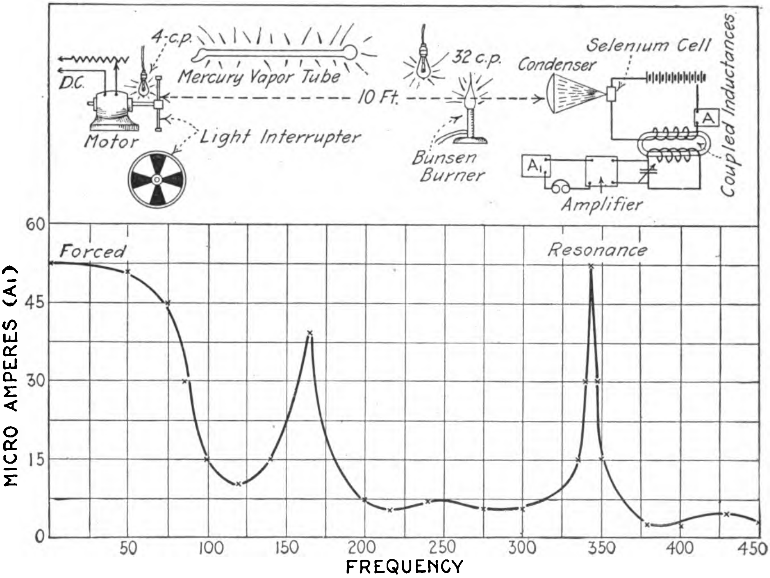

FIG. 22.
Resonance curve of the author's selenium, selective, light-wave, radiodynamic control system.

due to F. Lowenstein, was used, which, in turn, effected the operation of a telephone of the high resistance type, and a microammeter. With this arrangement the telephone signals received when the circuit and light interrupter were in resonant operation, were very loud, the interruptions of the light being heard as a clear musical tone, equal in frequency to the frequency calculated from the speed of the motor, and

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the number of blades on the shutter disc. The microammeter indicated a signal current of about 50 microamperes as the maximum value for resonance adjustment.

The selectivity was so good that it was difficult to keep the apparatus in tune, owing to slight variations in the speed of the shutter motor caused by changes in the line voltage. The resonance curve shows very clearly the degree of selectivity obtained. It is observed that when the frequency of the interruptions was between zero and about one hundred, the selective circuit was forced to vibrate in its own period, and the effect on the receiving instrument was practically as great as when the purely resonant operation occurred. The amplitude of the superimposed fluctuating current on the normal dark current in the selenium cell circuit, which contained a considerable ferric inductance, was probably 50 times greater for frequencies, say, below 100, than for frequencies in the neighborhood of 800, the natural frequency of the circuit during the test. This accounts for the fact that the indicator currents were so high with the forced operation in comparison with those of resonant operation. The fundamental vibration rate of the circuit at this particular setting was approximately 345 complete periods per second. The selectivity no doubt could have been improved upon by a better design of light interrupter, which would produce sinusoidal variation in the selenium cell's resistance, and by using inductances of less resistance than were used in this experiment.

Several electric lights in the room, including a mercury-arc light and a gas light placed directly between the condensing lens and the four candle-power light, did not materially affect the strength or quality of the received signals. It is believed that the distance could have been considerably increased or the intensity of the signal light reduced without greatly reducing the strength of the received signals. The

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telegraphic signals were sent with an ordinary Morse key connected in series with the signal light and operated according to the Morse or International codes.

Selective mechanically tuned elements were also tried in place of the tuned electrical circuit and an even greater degree of selectivity was obtained. These tuned elements were of the different types due to Ruhmer, Lowenstein, and Pickard, and are known as monotone amplifones or selective reed relays. A complete description is not permissible. The electrical circuit is, however, to be preferred for practical use on account of its nice adjustability and ease of handling, and because it is not, like the amplifone, subject to jars or sounds.

Although these experiments were rather encouraging, later tests made with a 24-inch searchlight during both day and night furnished conclusive evidence that, with the illumination furnished by such a source of light and the best selenium cells procurable, the operative range of such a system would not exceed a distance of one mile. The tests were therefore discontinued.

Ultra-violet Radiations

Ultra-violet light has a powerful effect in facilitating the discharge of electrons from negatively charged conductors and entirely overcoming the hindrance ordinarily experienced. The light waves may be conceived as shaking up the neutral atoms condensed around the electrons and setting the latter free.

Suppose we have two conductors in a vacuum at a difference of potential of, say, 300 volts, and that ultra-violet rays are made to fall on the negative wire. The negative electrons are set free to enter the vacuum and are repelled by the negative conductor; at the same time they are attracted by the positive conductor, and, since nothing prevents them,

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they pass from one to the other, and with a velocity of approximately 6600 miles per second. (See Fig. 23.)

Although we have but little data on distances at which these effects are observable, we know that they can be brought about, and a method of applying this property of ultra-violet light at once suggests itself.

In the "Electrische Zeitung," July, 1898, Prof. E. Zickler proposed to use this property of these radiations for teleg-

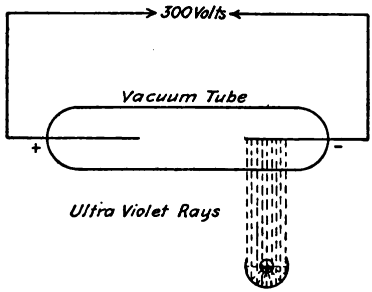

FIG. 23.

raphy. He succeeded on a small scale and believed that with a 25-ampere lamp and suitable reflectors, good results were possible over several kilometers. His proposal was based on an at first inexplicable phenomenon observed by Hertz. In the course of his experiments on resonance it was observed that the intensity of the sparks at the detector was greatly increased by placing a screen between it and the exciting spark. Later the curious effect was attributed solely to the ultra-violet rays emitted by the exciting discharger.

For such simple apparatus as that required for exploding mines where but one energy impulse is required, the problem is quite simple, requiring only an electric explosive cap in series with the battery and vacuum tube. When the rays are directed upon the negative electrode of the vacuum tube the discharge occurs immediately, and the current passing

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through the electric cap effects the ignition or detonation of the explosive material.

For the control of complicated mechanisms, however, a relay and some form of electric switching device are required.

Although ultra-violet rays have all the advantages of inaudibility, invisibility, and simplicity of generation and reception, in view of the known fact that the earth's atmosphere very strongly absorbs their power it is very probable that operation of such a system at useful distances would involve considerable difficulty.

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CHAPTER IX

EARTH CONDUCTION

The early suggestions of Steinheil and their subsequent application, as previously outlined, have been quite seriously considered as a very simple substitute for the comparatively complicated Hertzian wave apparatus for torpedo control. In view of the simplicity of the apparatus, and of the all-important problem of selective control offered by earth conduction telegraphy, experiments were conducted by the writer in Gloucester harbor (1912) to determine roughly its value for torpedo control.

The general plan of the proposed system is shown graphically in the accompanying drawing (Fig. 24).

Heavy insulated wires lead from the submerged plates to the station, where, by means of a switchboard, heavy currents can be sent between any two of the plates. The six different current fields thus capable of production are shown in the drawing by the curved lines.

The receiver comprises two conducting plates, one at the bow of the torpedo and one at or trailing behind its stern, with insulated conducting wires extending inside to the terminals of a sensitive relay. The necessity of so many current fields is obvious when we consider that we must be able to operate the sensitive relay regardless of the torpedo's direction of motion, *i.e.*, the direction of the current field must correspond to the direction of extension of the receiving plates. If means for accomplishing this are not provided it is possible to lose control of the vessel altogether.

The first thing to determine in these experiments was

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whether or not it would be possible to transmit enough energy to the receiver, at distances up to the limit of vision, with

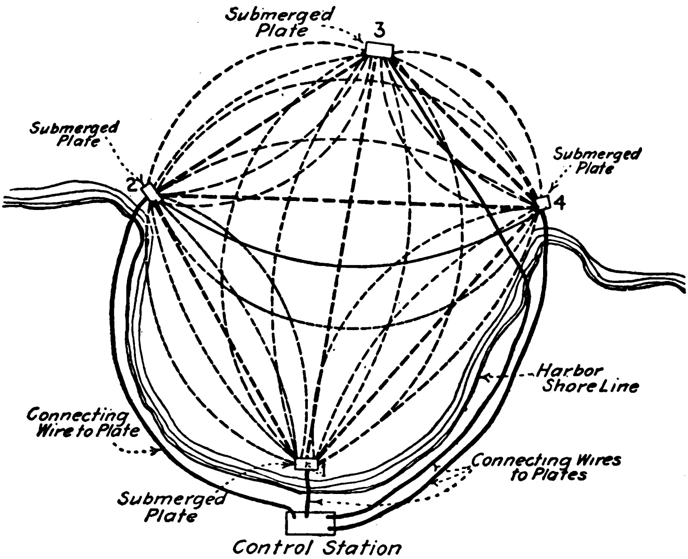

FIG. 24.

apparatus of such power as is consistent with practical considerations. With this end in view, apparatus was arranged as shown in the sketch (Fig. 25), which also shows the received

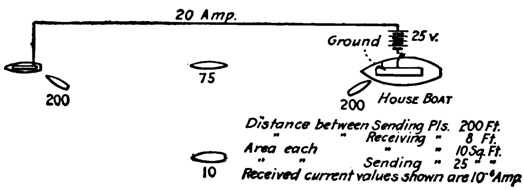

FIG. 25.

currents indicated by the Weston microammeter, for different positions of the receiving boat in the current field. This instrument was connected directly between the receiving plates which were fastened at the bow and stern of a ten-foot row boat.

The transmitter consisted of a 25-volt, 120-ampere-hour storage battery connected to two copper plates having an effective area of about 25 square feet each. One of these plates was the regular ground for the radio set aboard an 8-ton house boat; the other was fixed to the bottom of a row boat, moored about 200 feet distant.

A No. 16 bell wire, extending from the mast of the house boat down to the row boat, served to complete the circuit. The results are clearly shown in the drawing.

A very curious, unexplained phenomenon was observed during these tests. The readings were taken on transmitted impulses of about two seconds duration, with intervening periods of rest, and were made in response to signals, by an assistant on the house boat, who opened and closed the circuit *between the battery and the overhead line wire* extending to the distant sending plate. In this way one battery terminal was continually connected to the earth plate beneath the boat.

In addition to the usual earth current — these currents may be found almost anywhere on the surface of this earth and were in this case of course independent of the sending battery — readings were obtained which varied up to 50 microamperes according to the position and direction of extension of the receiving boat; *and these readings gradually increased as the receiving boat neared the house boat.* When the house boat plate was disconnected from the storage battery the received current dropped to the normal value. Signals could thus be sent, up to distances of about 50 feet, simply by making and breaking the connection between the battery and plate, with absolutely no current flowing from the battery. The arrangement of apparatus and results are shown in Fig. 26.

The following day (Sept. 1, 1912) further tests were made with increased power and distance. The transmitting current

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was obtained from a bank of four 110-volt, 50-ampere mercury-arc rectifiers, regulated by a series resistance, and measured by an ammeter. The respective areas of the transmitting

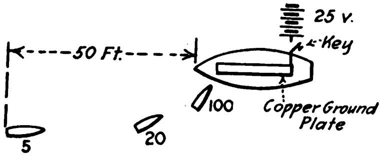

FIG. 26.

plates as well as the distances between them are given in the drawing (Fig. 27). The leads to the earth plates of the transmitter were composed of twenty-foot sections of No. 20 copper strips, one and a half inches wide, soldered together.

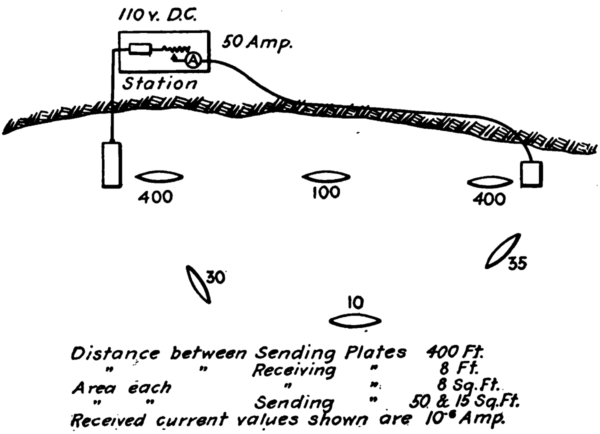

FIG. 27.

The maximum current obtainable was 50 amperes, and the received current values shown were secured with this transmitting current.

On Oct. 3, this distance was again increased, this time to approximately 1000 yards between the sending plates. Fig. 28 shows the results of this test.

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The received current values resulting from these different tests show that, in a line between the two transmitting plates, the position of the receiving plates for weakest signals is midway, and for strongest, nearest either of the plates. With

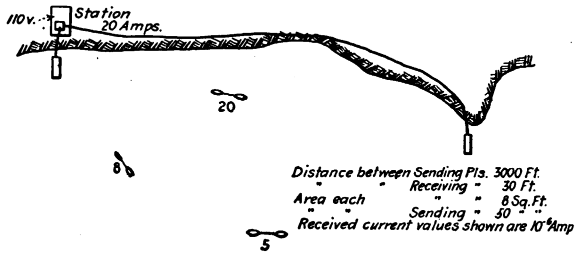

FIG. 28.

a transmitting power of over five kilowatts, the received currents at the position of minimum signal strength (which is the distance determining factor), that is, at a distance of less than one-half mile, were no more than sufficient to operate a

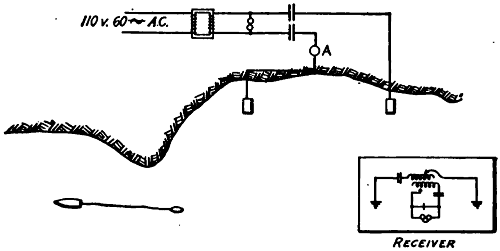

FIG. 29.

sensitive relay of the type necessary for torpedo control. These results were far from encouraging and the tests were discontinued.

A somewhat different scheme due to Mr. H. Christian Berger, an electrical engineer of New York, was next tried. The transmitting energy was a high-frequency oscillatory cur-

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rent, and the receiver was of the regular radio type, with two earth connections instead of one earth and one aerial.

The earth plates were of copper, 100 and 25 square feet area, respectively, separated 400 feet, and connected, as shown, in series with the oscillating condenser circuit. A hot wire ammeter in this circuit indicated a current of four amperes. The primary energy was delivered to the condenser circuit by a 3-kw., 110 to 20,000-volt, 60-cycle transformer. (See Fig. 29.)

The receiver connections, illustrated in the small drawing at the right, are those of a common radiotelegraphic receiver with the exception previously noted. The distance between the receiver grounds was about 250 feet, and the distance between the two sets of grounds of transmitter and receiver was estimated at about 500 feet.

Dr. L. W. Austin, head of the U. S. Radio Laboratory in Washington, D. C., has shown that a radiotelegraphic sender may exert a very large amount of power for the brief periods of time during which the condenser discharges.

Considering a condenser of 0.04 mfd., charged to a potential of 10,000 volts, Q is equal to $\frac{0.04}{1{,}000{,}000} \times 10{,}000$, or 0.0004 coulomb.

The work done in charging such a condenser to that potential is equal to $\frac{V^2C}{2}$, or $\frac{10{,}000^2 \times 0.00000004}{2}$, or 2 joules, or $0.737 \times 2 = 1.47$ foot-pounds. It can furnish that amount of energy in one discharge.

If the condenser is discharged through a circuit of such self-inductance as will give a wave length of 1000 meters, the oscillation frequency will be 300,000, and the alternations 600,000 per second. 0.0004 coulomb will create an average current of $0.0004 \times 600{,}000 = 240$ amperes. Were the wave length much shorter the current would be correspondingly greater, as is shown by the following example.

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The above condenser is discharged through an inductance which will give a wave length of 500 meters. The alternation frequency of this circuit would then be 1,200,000 per second. 0.0004 coulomb will create an average current of 0.0004 × 1,000,000 = 480 amperes. By this we see that the current in an oscillatory circuit is inversely proportional to the wave length.

If the energy of 2 joules stored in the condenser is radiated in five complete oscillations, the rate of doing work, if the efficiency of conversion is unity, is 2 joules in $\frac{5}{600,000}$ second = 240,000 per second = 240 kw. This shows very clearly that although the available energy is very small, the rate of doing work, *i.e.*, the power of a wireless telegraph sender, may be very great for a short period of time.

This peculiarity of a condenser discharge is, no doubt, the basis for Mr. Berger's suggestion. The scheme is distinctly novel, utilizing, as it does, oscillating currents of high frequency, but with earth conduction, and not etheric radiation, as the means of transferring the energy.

The tests given this system were very severe in that the conditions imposed were far from ideal; but at that time it was believed that if no *telephone* signals could be received under those conditions, the system would be valueless for *relay* operation. No signals were received during this test and the experiments were discontinued.

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CHAPTER X

ELECTROSTATIC AND ELECTROMAGNETIC INDUCTION—HERTZIAN WAVES

Following the scheme of Dolbear, the author experimented with electrostatic induction as a possible means of torpedo control at the Hammond Radio Research Laboratory in 1912.

The transmitter consisted of a 100,000-volt transformer, especially built for the purpose, energized by alternating current of from 60 to 1000 cycles. One terminal of the

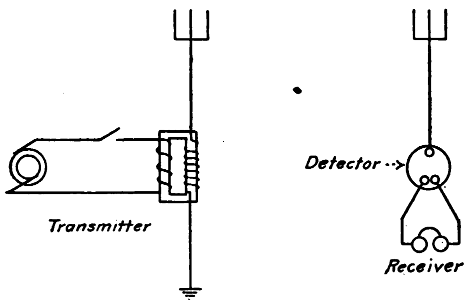

FIG. 30.

secondary was grounded, and the other connected to the station antenna,* which was insulated for 1,000,000 volts with Electrose strain insulators.

The receiving apparatus consisted of an antenna,† on the house boat *Pioneer*, connected to a very sensitive form of potential operated radio detector which will be more fully described in a subsequent chapter.

Fig. 30 shows schematically the circuit arrangements.

* 300 ft. high, 400 ft. flat top. † 30 ft. high, 20 ft. flat top.

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The curve, Fig. 31, was made by taking readings of the received currents, as indicated by a Weston microammeter, connected to the receiving detector. The *Pioneer* was started seaward within about a hundred feet of the transmitting station, and readings taken every minute near the shore; after the steeper part of the curve had been passed the readings were taken at longer intervals.

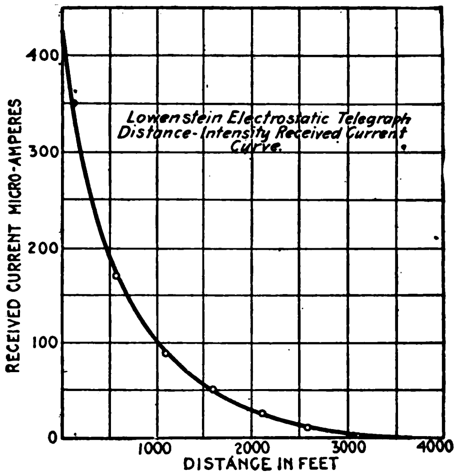

FIG. 31.

An attempt at tuning the receiver to the frequency of the alternating current used at the transmitter was made by introducing a variable inductance of large value and a tuning condenser in series with the antenna, and connecting the detector to a point of maximum potential in this circuit. Fig. 32 shows this circuit.

The transmitter was then changed to the regular radio type, the wave length being pushed far beyond the natural period of the antenna by means of loading inductances in both open and closed circuits. This was done to increase the potential to the highest possible value, in order to in-

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crease the distance of operation. With an emitted wave length of about 3000 meters, the potential was slightly increased over that previously obtained with the transformer, but no material increase in received results was noted. The group frequency was 120 per second. In order to measure the electrostatic effects alone, no tuning to the high frequency oscillations was attempted, the receiving antenna being

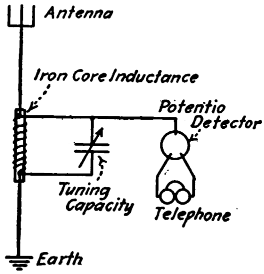

FIG. 32.

connected only to the detector. The low-frequency tuned antenna circuit was then substituted for this receiver as before. The curve obtained in the best series of tests (Fig. 31) shows that with our very sensitive relay operating under working conditions, the maximum range would be only up to about 1000 feet, a distance far too short for torpedo operation. This method of control was also abandoned.

Electromagnetic Induction

Beyond the work of Preece, Trowbridge, Edison, and others, already mentioned, very little has been done in the field of electromagnetic induction for radiodynamics.

The fact that the transmitting and receiving coils or line wires must be in parallel planes is one of the chief objections to this system for transmitting energy impulses to a movable boat.

The writer has not been able to find any accounts of work

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along this line. Although the difficulties are not in themselves insuperable, from a practical point of view they have been considered too great in comparison with other systems. No effort therefore has been made to utilize electromagnetic induction as a means of controlling dirigible, self-propelled vessels.

Hertzian Waves

Hertzian waves, as every one knows today, are by far the most important means of wirelessly transmitting energy, either for the communication of intelligence or for the control of self-acting apparatus of whatever nature. We are not so much interested in presenting historical matter pertaining to the very large amount of work done since Marconi's first experiments; nor do we wish to burden the reader with detailed theoretical or practical considerations of the many phases of the radio signalling art, it being assumed that he is sufficiently acquainted with the art as it now stands to understand the accounts of its special application in the comparatively new field of radiodynamics; these special applications will be hereinafter described in sufficient detail to be readily understood by those possessing some knowledge of electricity.

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CHAPTER XI

THE ADVENT OF WIRELESSLY CONTROLLED TORPEDOES

Although the subject of this chapter does not include torpedoes in general, it is nevertheless important to have some knowledge of the ordinary torpedo, and some facts pertaining to its advantages and disadvantages, if we wish to obtain a clear conception of the wirelessly controlled weapon now being perfected for modern naval warfare.

The torpedo is claimed to be an American invention, being said to have sprung from the fertile brain of Benjamin Franklin, who, during the Revolution, experimented with this then unheard of method of marine attack. The first attempt in war of which we know was made in the harbor of Brest, on the west coast of France, in 1801, under the orders of Napoleon. This first test under actual war conditions was made by an American, Robert Fulton, the father of steam navigation. Fulton used a submarine boat, the drawings and designs of which have never been published. He is said to have obtained considerable success in his experiments, but he failed in an attempt to blow up an English man-of-war, whereupon Napoleon withdrew his support, and the scheme was not carried into practical operation.

We next hear of torpedoes in the Russian war of 1854, when one of prodigious power was exploded in the harbor of Cronstadt, through copper wires connecting with a galvanic battery on shore.

Again, during our own Civil War, the torpedo made its appearance in improved form. It was employed for harbor

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defense chiefly in and around Charleston. It was also used with deadly effect during the Spanish-American War, and, in the hands of the Japanese, inflicted great damage to the Russian fleet in the battle of Fuishima Straits.

Every modern battleship is equipped with from two to four torpedo tubes. The United States alone has over 60

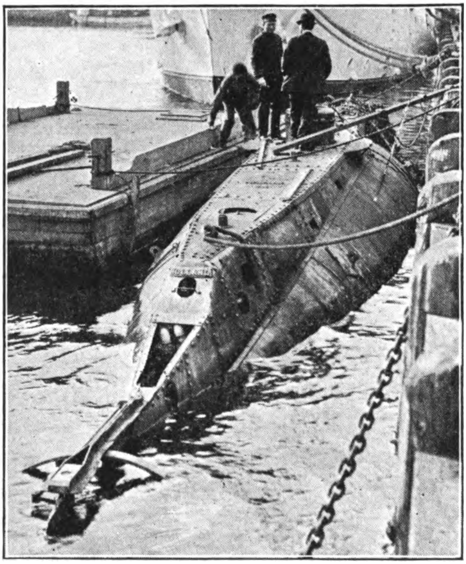

FIG. 33.
The first Holland submersible.

torpedo boat destroyers, 30 torpedo boats, and 50 submarines, representing a cost of at least fifty million dollars and manned by over three thousand officers and men.

The modern torpedo, for the handling of which all these vessels have been built, is about eight feet long and nearly two feet in diameter at the largest part. It is propelled by a compressed-air motor fed from tanks containing air under about seventy atmospheres pressure, and is kept laterally

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stable, and on its intended course by a gyroscope. It has a speed of from twenty-five to forty knots, a range of from one

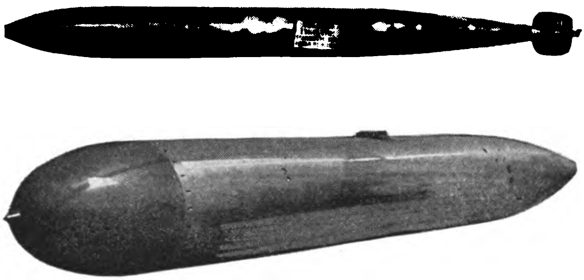

FIG. 34.
Types of torpedoes.

thousand to four thousand yards, and carries from two to three hundred pounds of highly explosive material, usually gun-cotton. It is launched from a "torpedo tube," a form

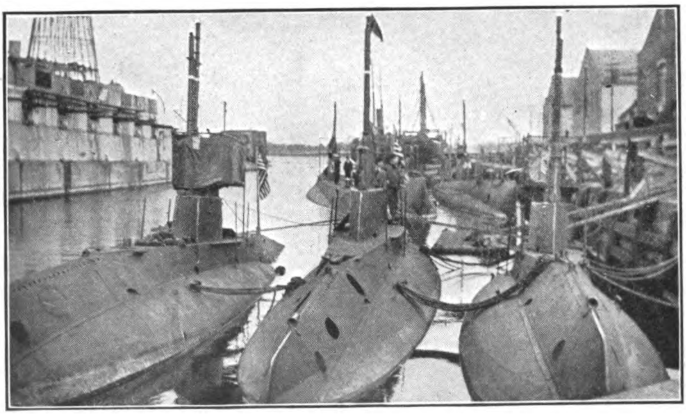

FIG. 35.
Modern U. S. submarines.

of compressed-air gun, which on battleships and submarines is submerged, and on torpedo boats and destroyers is so

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mounted on deck that the missile can be fired in the desired direction without swinging the ship. Figs. 33 to 39 will aid

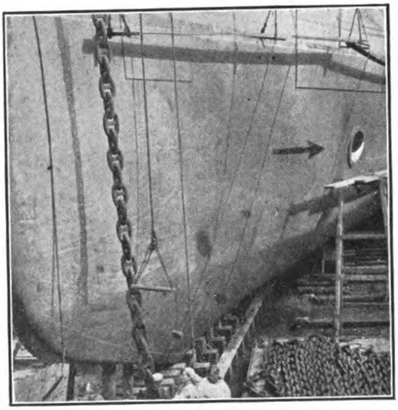

FIG. 36.
View of a battleship in a dry dock showing submerged torpedo tube.

in making clearer the explanations relating to torpedoes and to the different types of ships upon which they are used.

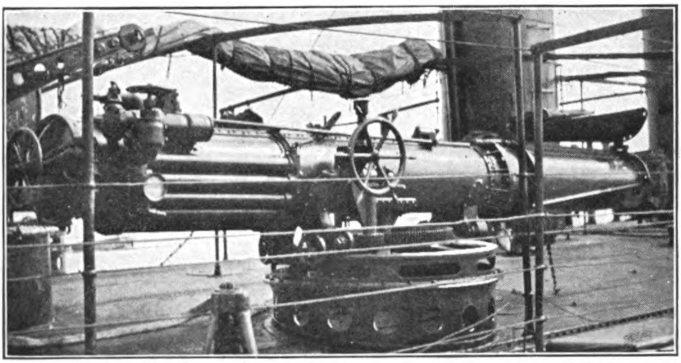

FIG. 37.
Deck type of torpedo tube used in launching torpedoes from torpedo boats.

Before actually firing a torpedo allowances must be carefully made for such variable factors as speed and direction of

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both the target and the firing ship, the direction and velocity of the wind, and the condition of the sea.

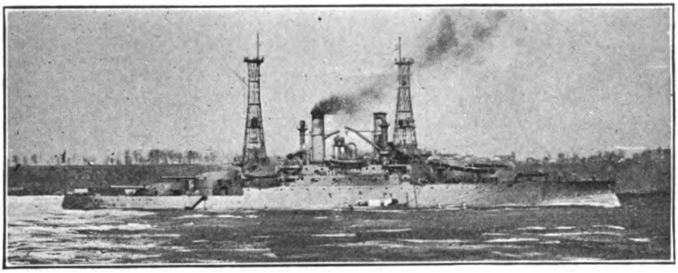

FIG. 38.
U. S. S. South Carolina equipped with two submerged torpedo tubes.

The percentage of hits at the extreme range of four thousand yards is not greater than twenty-five; and when the sea is disturbed, even at much shorter ranges the accuracy is still less.

The torpedo boats of both surface and subsurface types are chiefly relied upon to do the torpedoing, and, because of the

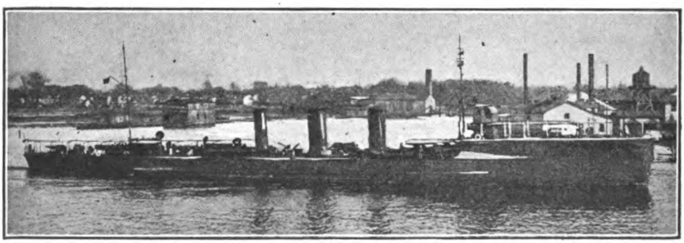

FIG. 39.
Torpedo boat destroyer entering Norfolk Navy Yard.

fact that in order to do accurate firing the distances must not be great, these vessels are subject to the very hot fire of the enemy's torpedo defense battery of three- and six-inch guns. The torpedo attacks are, however, usually made under

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the cover of darkness or fog; this fact, coupled with their great speed and small size, is their only protection. If they can approach near enough to discharge accurately a torpedo before being discovered and illuminated by the searchlights of the enemy, all is well; but if not, it is probable that their thin hulls will be riddled with three-inch shells before they can escape.

The principal advantage of the ordinary torpedo is that usually with one well-directed shot, a small, comparatively inexpensive craft carrying from ten to fifty men can totally, or at least seriously, disable a huge fighting machine like a modern dreadnought, carrying a thousand men and costing from five to fifteen million dollars. Its disadvantages are principally the great risk to human life accompanying its use, the comparatively poor accuracy of the firing, and the fact that if a shot is a failure, the five thousand dollar torpedo cannot be recalled.

In the year 1897, when wireless telegraphy was still in its infancy, Ernest Wilson, an Englishman, was granted a British patent on a system for the wireless control of dirigible, self-propelled vessels. The primary object of this invention was to provide a weapon for use in naval warfare, which, if in the form of a dirigible torpedo, controlled from a shore or ship wireless installation, would be most deadly in its effect on a hostile fleet. No mention has been found of actual apparatus constructed according to Wilson's plans.

To Nikola Tesla, probably more than to any other investigator, belongs the credit of first constructing a dirigible vessel which could be controlled from a distance without connecting wires. His experiments were begun in 1892 and from that time on he exhibited a number of wirelessly-directed contrivances in his laboratory at 35 South Fifth Avenue, New York City. In 1897 he constructed a complete automaton in the form of a boat (Figs. 40, 41 and 42), which would steer itself in obedience

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to guiding impulses of Hertzian waves sent out from shore. On Nov. 8, 1898, he was granted a United States patent on this invention. In this patent he mentions the use of all

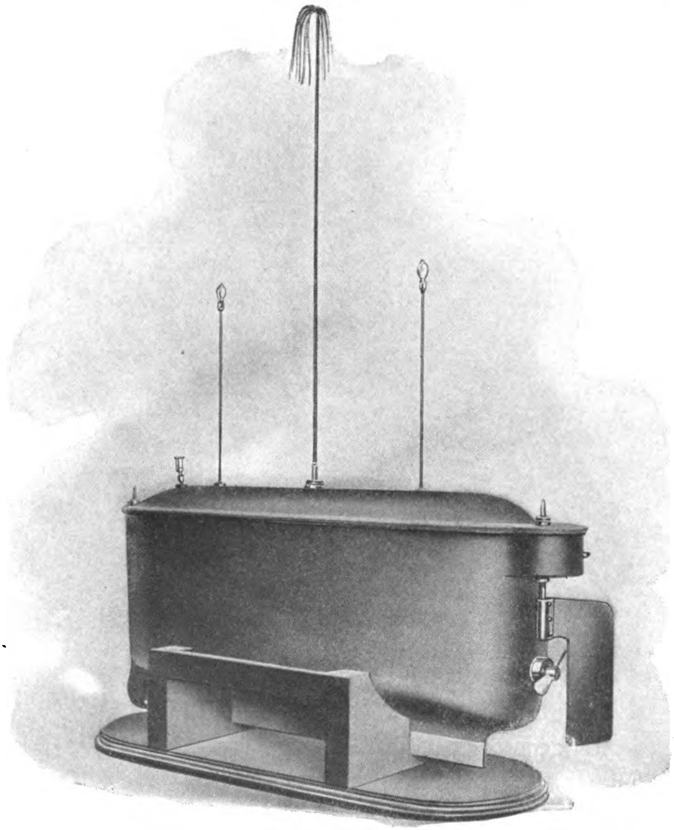

FIG. 40.
Nikola Tesla's telautomaton, controlled by Hertzian waves, which is the first radiodynamic boat.

forms of control energy including electromagnetic induction, electrostatic induction, conduction through earth, water, and the upper atmosphere, and all forms of purely radiant energy.

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The drawings, of which there are ten, illustrate in detail the nature and arrangement of the apparatus. These drawings were made to scale from the completed model, which he had in operation at that time.

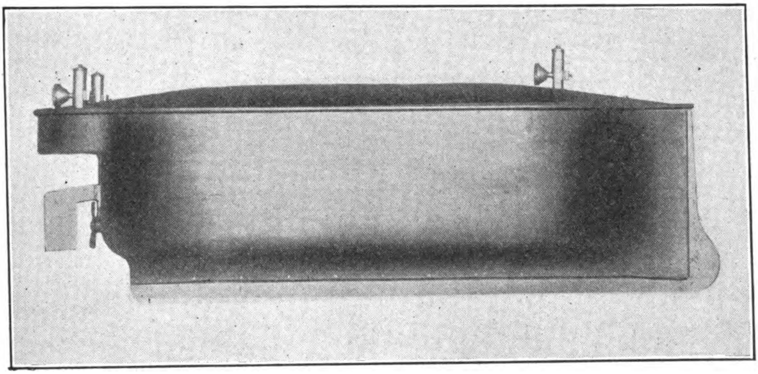

FIG. 41.
Side view of Tesla's boat.

Wilson's was the pioneer patent in that branch of radiotelegraphy now known as radiodynamics. Since then a large number of patents in this field have been taken out by various inventors, and several of those who have been so fortunate

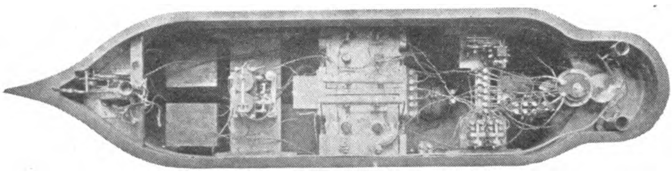

FIG. 42.
Interior view of Tesla's model radiodynamic torpedo.

as to secure the means, have developed their respective systems in the effort to realize their possibilities.

Gardner of England, Wirth, Beck and Knauss of Germany, Gabet and Deveaux of France, Roberts of Australia,

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and Tesla, Sims, and Edison of the United States have during the last fifteen years attempted to solve the problem in a practical way. All of these investigators save Roberts, Simms, and Edison have applied their systems on boats intended primarily for torpedoes, which they control by Hertzian waves. Sims and Edison, with the coöperation of the United States Government, developed a system for

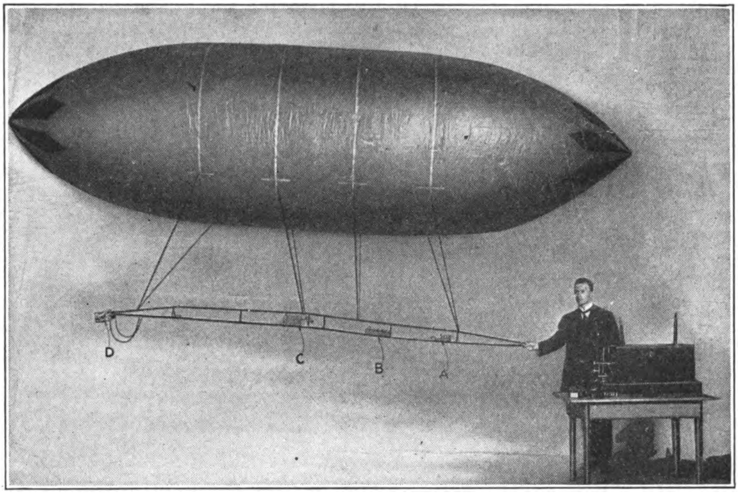

FIG. 43.
Roberts's (Australia) wirelessly directed airship exhibited in 1912.

controlling a dirigible torpedo through a trailing conductor, and Roberts has applied his system to dirigible balloons. Fig. 43 shows A. J. Roberts and his wirelessly-controlled airship as it appeared on the lecture platform. The twelve-inch induction-coil transmitter may be seen at the right on the table. At *A* is the coherer, tapper, relay, and coherer battery; at *B* is a rotary switch of the Tesla type; at *C* are several cells of a storage battery and two signal lights; at *D* are two propelling and steering motors which are mounted at the ends of a

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centrally-pivotted, horizontal frame about two feet long. When both are rotating the airship moves directly ahead. Steering is accomplished by stopping one of the motors. A single wire about 4 feet long serves as the antenna. The length of the airship is 15 feet and the weight is approximately 16 pounds. The gas bag consists of four layers of pig intestine. The intestines of over 4000 pigs were used in the construction of this bag. The maximum control distance is about 500 feet.

These inventors have had various degrees of success in their endeavors to perfect their inventions, but apparently none have reached the goal. It is true that they have controlled the movements of vessels from a distance without the aid of conducting wires, but at best the apparatus has worked spasmotically, unsatisfactorily, and the greatest distance at which their vessels have been controlled has not exceeded one-half mile. But why, we may ask, have these able experimenters failed to secure the desired results when wireless telegraphy, the mother of radiodynamics, has made such wonderful progress?

On analyzing the situation we find that early in the art potential-operated receiving devices, such as the coherer, were used, which permitted the use of recording mechanisms. As the art progressed new receptive devices were discovered which, in connection with the marvellously sensitive telephone, proved the coherer comparatively insensitive and unreliable. Coherers were then discarded and replaced by the detectors and telephones, which provided a means of signalling over vastly greater distances with the same transmitting power as before. The new detectors, while forming a very desirable combination with the telephone, were entirely unsuitable with relays, and, therefore, those interested in the control of mechanisms were compelled to retain the coherer as the receiving detector. This is the reason for the poor success attained in the field of radiodynamics. The coherer, being

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capricious in its action, sometimes operates when the transmitting key is closed, and sometimes when no signals are sent, possibly steering the boat to starboard when the signal should have turned her to port, or stopping the engine when full speed was desired. The coherer, because of its unreliability has heretofore been the barrier to the full realization of the invention's possibilities.

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CHAPTER XII

SELECTORS

We have already discussed the possible control methods for use in radiodynamics. The function of these, as has been pointed out, is to operate an electromagnetic switch, or relay, as it is called, from a distance. We have also shown how selectivity in the operation of a relay can be secured by an application of the familiar principles of resonance; for example, the methods of tuning in radiotelegraphy to periodically recurring characteristics of the emitted wave energy.

Since there are a number of mechanisms to be controlled, each with a distinct operation to perform aboard the torpedo, it is evident that we must have either a separate receiver and relay for each mechanism, or else some kind of selector apparatus controlled by a single receiver and relay. As pointed out by Hammond, we can, therefore, make two broad classifications of the control systems, namely, (1) monopulse, those in which a single kind of impulse controls a single relay, which, in turn, controls a means of selecting the desired circuit, and (2) polypulse, those in which a different kind of impulse and a separate receiver and relay are used for each circuit to be controlled.

A further classification, depending on the type of relay-controlled selector used by various experimenters, follows; this classification also has two main heads, namely, (*a*) those systems involving the time factor in impulse emission, and (*b*) those independent of the time factor.

Under *a* we have:

(1) Blondel's, Gray's, and Mercadier's methods of con-

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trolling separate mechanisms by the use of tuned mechanical or electrical elements at the receiver, and a transmitter capable of transmitting impulses of varying group frequency.

(2) The author's system which utilizes a method of operating separate mechanisms by impulses of different length.

(3) The author's method of using a transmitter of variable impulse frequency and a receiver with a solenoid of high self-inductance in which the current is made to vary by change of impulse emission rate so that its core can be made to assume any one of a number of positions.

(4) Gardner's system in which the ratio between the length of impulses and of the intervening periods of rest is varied, and in which a solenoid is used at the receiver, its core assuming a definite position for each value of that ratio.

Under *b* we may place the following:

(1) Tesla's method which uses one type of impulse to control a number of different mechanisms, as a clock fitted with a hand, which, operated from a distance, could be made to stop on any five-minute point, the hand needing to pause say two seconds before the energy would be exerted.

(2) Walter's method, which depends on synchronous mechanical rotation; as two clocks, one at the transmitter and another at the receiver, each fitted with a hand, which moved synchronously over their respective dials, and so arranged that when the transmitting hand is depressed and stopped, say, at the figure six, an impulse will be sent out that effects the pulling down and stopping of the receiving hand which is also at six, thus closing the circuit; when the transmitting clock hand is raised, the impulse ceases and both then resume their synchronous rotation.

(3) There is still another method upon which modern automatic telephone systems are based, namely, the method of closing any one of a plurality of circuits by sending the correct number of impulses; for example, we have a square figure

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divided into 100 equal squares; beginning at the lower left-hand square let us number it 0, the next above it 1, the next 2, and so on up to 9; then let the square at the right of 0 be called 1, the next beside it 2, the next 3, and so on to 9; the squares above these are numbered in exactly the same way, that is, the columns are all of the same figures. We have a checker normally at the 0 position that can only be moved twice to place it in any square, and only in two directions, *i.e.*, up, and to the side. Now in order to get our checker in space 67, for instance, we move it six blocks up and seven to the side. In the case of the 100-circuit selector illustrated by this checkerboard, two different sets of impulses are necessary, one which effects the raising of the contact arm to the desired row, and another to move it laterally to the position desired.

Among the earliest devices we find that of Tesla, used also by Orling and Braunerhjelm, Jamieson and Trotter, Roberts, and Varicas, employing a form of rotating commutator or its equivalent.

Of these, Tesla's, Varicas', and Roberts' only have been actually put in practice. Varicas' boat carried out in 1901 the simple steering evolutions required but the apparatus was quite unprepared to cope with intentional interference. Roberts, as before stated, applied his system in 1912 to a small dirigible gas balloon for theatrical exhibitions. None of these operations were carried on at any considerable distance, probably not farther than a few hundred feet, but no authentic data is available. All employed the primitive filings coherer.

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CHAPTER XIII

EUROPEAN CONTROL SYSTEMS

The following extract from an article on "Telemechanical Problems in the Wireless World," by L. H. Walter, M.A., taken with the kind permission of the author, describes some of the systems experimented with in Europe during the past 15 years.

Walter's Selector System

"As an example of codal selectors the system devised by the writer in 1898 may be taken, not because it is considered the best — for the writer is prepared to admit that in its early form it left something to be desired — but because it is practically the earliest comprehensive method, and also because it has served as a model upon which numerous later systems have been founded, such as those due to Chimkevitch, to Hülsmeyer, Branley and others. The system was worked out as a selecting device suitable for *any* telemechanical, as opposed to telegraphic purpose, although Righi and Dessau in their 'Telegraphie ohne Draht,' and also Mazzoto in his book, describe the writer's arrangement as though it were to be used for selective wireless telegraphy, like the later system of Anders Bull, which has many points of similarity. The original idea involved the use of synchronous rotating discs at the sender and receiver, both released by the act of sending a preliminary signal. One complete revolution of the disc then resulted, if no further impulses were received, and the arrangement was then in its initial receptive state. The receiver disc comprises a number of contact studs placed on the periphery

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of the disc, corresponding to the code signal selected for one circuit; these studs are all connected with a safety device. If during the disc's rotation impulses are received when the contact brush is exactly on one of the studs so connected, the safety device has its circuit closer advanced one step for each such correctly timed impulse, and finally makes an operative contact when the desired evolution (steering, firing, etc.) is carried out. Should, however, any impulses arrive when the brush is not on a codal stud, the safety device flies back to its initial position, thus preventing the actuation of the apparatus by unauthorized or interfering impulses. It is well understood that the transmitter has as many codal discs as there are circuits to be controlled, and there are a corresponding number of safety devices. Special relays are also used for the purpose of stopping an evolution when the next evolution is one which cannot be carried out without conflicting with the first (*e.g.*, 'helm to port' and 'helm to starboard').

"Although apparatus of this type was kept at work in the author's laboratory for several years it has never been fitted on an actual boat, owing to the fact that the idea appeared to be before its time, as people at that date were not inclined to take even wireless telegraphy very seriously. Hülsmeyer's system, however, which dates from 1906, and is practically identical with that of the writer, was tried in Germany on a practical scale, and is said to have proved satisfactory, although it has not been possible to obtain any further particulars. The much-discussed system due to Professor Branley is also carried out on almost identical lines; his earlier arrangement of 1906 being later completed, in 1907, by the addition of a safety device like that of the writer."

Gardner's Torpedo Control

"The highly ingenious system devised by J. Gardner appears to have been the first comprehensive arrangement to be

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put into operation on a practical scale, and has proved to be one of the most thoroughly reliable methods of controlling vessels by means of wireless impulses.

"At the first glance the apparatus, which is based upon an application of Watt's centrifugal governor, appears to be unlike any of the other systems; but on looking at it from the point of view of a selecting system it is clear that the device combines the properties peculiar to both the classes as already defined. The governor, with its hinged balls maintained near the axis by means of a spring, is normally stationary, in which condition the sliding collar on the spindle is in the rest position, and all circuits are open. When impulses are received from a suitable transmitter, a step-by-step arrangement causes the governor spindle to rotate; the governor balls tend to fly out against the action of the spring, and the collar moves along the spindle, carrying with it a contact brush which is able to pass over a series of contacts connected to the various circuits to be controlled. When the periods of impulses and no impulses are equal, the governor maintains a constant speed, and it is thus possible, by varying the relative durations of the impulse periods and the periods of etheric silence, to make the contact brush pass on to any required contact, and to maintain it there. At the highest speed of rotation the firing contact is made.

"One of the chief advantages of this system is that, should anything go wrong, the 'off' position is reverted to automatically, and the torpedo comes to rest.

"By the kindness of Mr. J. Gardner the writer is able to give a photograph of this interesting dirigible torpedo, which is the only British wirelessly controlled craft that has stood the strain of actual tests. Although these trials were carried out when there was quite a lot of shipping about, there has never been any mishap and this the inventor attributes to the simple property possessed by the system of causing the

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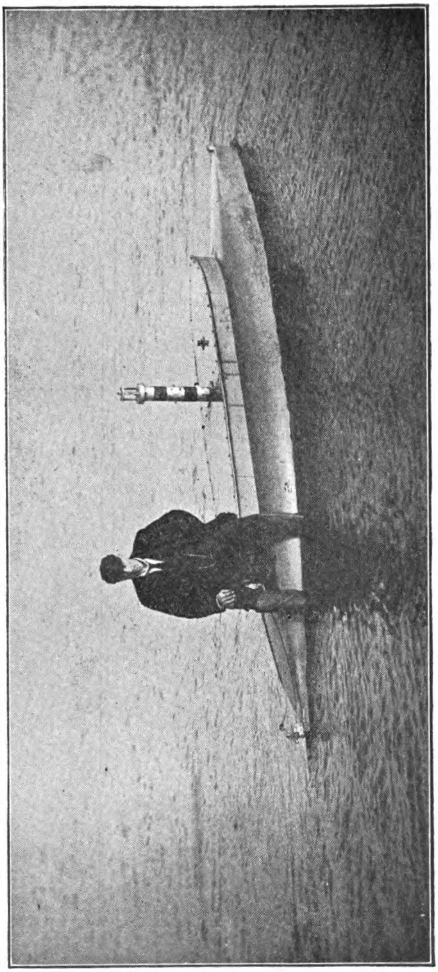

FIG. 44.
The only British radiodynamic torpedo that has stood the strain of actual tests.

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vessel to rest when the impulses cease. The short funnel which will be noticed in the photograph, Fig. 44, is for the escape of battery gases; the aerial being supported from a pole which fits in the socket just forward of the funnel."

Deveaux's Dirigible Torpedo Boat

"The method adopted by Lalande and Deveaux is exceedingly simple, but the boat represents the most ambitious attempt in the history of wirelessly controlled apparatus. The selector system comprises (1), a circular distribut-

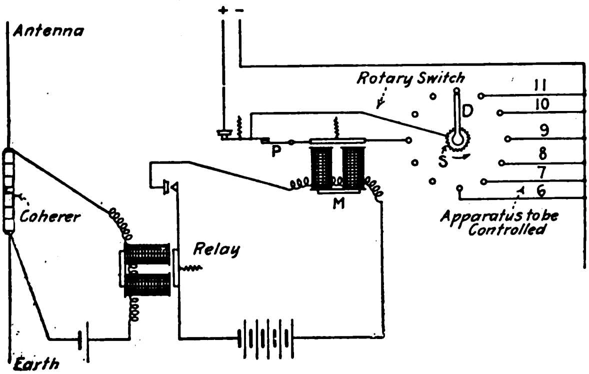

FIG. 45.

ing switch, having on it the studs pertaining to the circuits to be controlled; and (2), a circuit closer which only allows the current to pass when the distributing switch arm has reached the desired contact stud. In the actual apparatus the distributing switch has twelve studs, of which nine lead to the nine operating circuits employed; the remaining three are distributed among the others and constitute rest positions with a view to saving the switch arm from having to execute a complete circle each time. Fig. 45 is a diagram of the connections.

"In order to carry out the double function mentioned, an

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electromagnet M is provided which moves forward by one tooth at each Hertzian impulse, a twelve-toothed step-by-step arrangement connected to the distributor arm D. During the period when this arm is being advanced, no closing of the operating circuits is possible owing to the circuit closer being opened by means of a projection on the end of the armature of the electromagnet; this is shown at P. Thus if twelve impulses are received, the distributor would describe a complete revolution. On the other hand, if the impulses cease after the distributor has been carried from a rest stud to one of the operative studs, the circuit closer will complete the circuit after a brief interval of time, which is caused to elapse owing to the intervention of a retarding device. This latter consists of a train of clockwork, which, by virtue of its inertia, does not allow the circuit closer to operate at once; a delay of twice the time required for the distributor to be moved forward by one tooth has been found sufficient. M. Deveaux's paper, which was published in the Bulletin of the Societé Internationale des Electriciens, in 1906, will be found to give full information as to the circuit arrangements, but no illustrations of the boat itself.

"By the courtesy of M. Montpellier, the editor of l'Electricien, the writer is able to make good this deficiency, and to give two photographs of this craft; Fig. 46 shows the vessel when hoisted out of the water, and Fig. 47 gives a general idea as to its appearance and the visibility of its antenna when afloat; the French cruiser Saint Louis, shown in the background, was watching the trials which took place off the port of Antibes in the early part of 1906.

"The boat itself, which weighs 6700 kg., consists of two cigar-shaped bodies formed of steel plate, one above the other on the principle of the Sims-Edison dirigible torpedo. The upper cylinder, 9 meters long by 45 cm. in diameter, acts as a float; it is provided with two small masts, which serve

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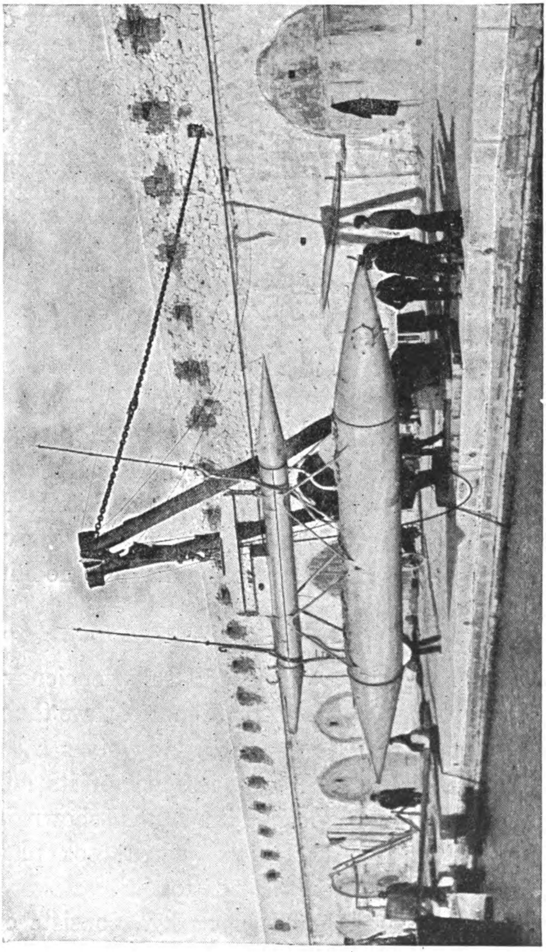

FIG. 46.
The most practical torpedo as under wireless control in 1906 (control perfected since).

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to support the wireless antenna, consisting of five wires kept at a height of about three meters; and these masts have lamps about halfway up, for the purpose of facilitating steering operations. The lower cylinder is 11 meters in

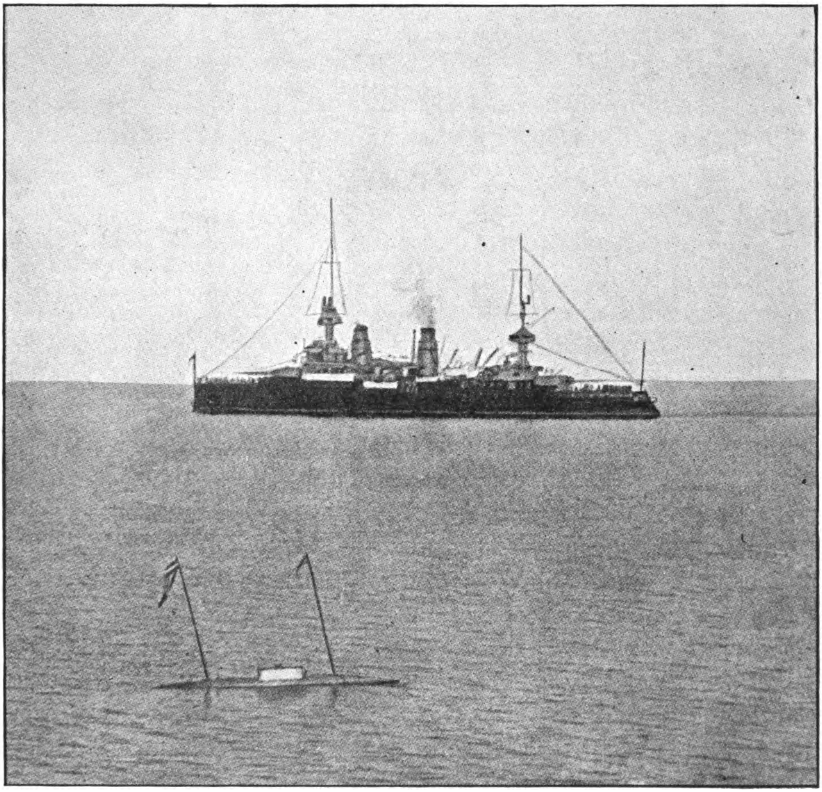

FIG. 47.

length, and 1 meter in diameter, and contains the torpedo-ejecting tube and a Whitehead torpedo of 450 mm. diameter; the accumulator battery and propelling motors are also contained therein. The control apparatus is intended to be placed in the lower cylinder, where it would be protected

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from the enemy's gunfire by two meters of water, but in the trials the apparatus was placed in a sheet metal box on the top of the upper cylinder in order to be available should any adjustments be required. The trials were carried out over a comparatively short radius, 400 to 1800 meters, but it is stated that these distances could easily have been exceeded though to what extent is not said.

"The transmitting station from which the boat's evolutions were controlled was on land, and had a five-wire antenna 15 meters in height; but no information is available as to the actual wave length employed, although, from the size of the receiving antenna, it was probably very short, of the order of 80 to 100 meters."

Wirth, Beck and Knauss

Remarkable achievements in the line of torpedo control have been accomplished in Germany, where two unmanned motor boats 33 and 50 feet in length have been steered, stopped, started, and controlled in every way by electric waves transmitted from the shore without the use of wires. The system employed is the invention of C. Wirth of Nuremberg. It has been brought to its present stage of development by several years of experiment, conducted by Wirth and his coöperators, the manufacturer Beck and a merchant named Knauss; it is protected by numerous German and foreign patents.

The first success was attained in 1910 with an electric launch on a lake near Nuremberg. The vessel was 33 feet long, and was propelled by a 5 horse power motor, and an accumulator battery of 80 volts and 300 ampere-hours. The first public demonstration was given with this boat in 1911 before the German Fleet Club; in this demonstration the unmanned boat fired a signal shot and then set itself in motion. Travelling at a speed of about 10 miles it was made

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to turn right or left or to stop completely and start again by the controlling operator in obedience to the requests of members of the Fleet Club. Each order was obeyed within from one to five seconds, and signal lights flashed back the receipt of the impulses. The manuevers were continued for several hours.

A boat 50 feet in length was later exhibited in Berlin, at the invitation of the German Fleet Club. An antenna of

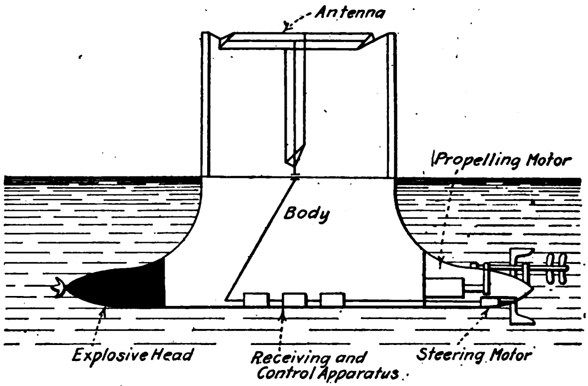

FIG. 48.
Proposed form of Wirth radiodynamic torpedo.

four wires was stretched between the cupola of the Kaiser Pavillion and the restaurant on the shore of Lake Wann. The transmitting apparatus which was installed at the restaurant was of the induction coil type, and was of about 100 watts capacity. The various operations performed on the boat were accomplished by sending impulses by means of a Morse key. The boat was equipped with an antenna of four wires about 15 feet high, a radio receiver capable of adjustment to different wave lengths from the transmitter, a distributor or selector, electric steering apparatus, signal guns, lights, and fireworks apparatus. The tuning of the

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apparatus could be altered by sending a long signal; this was for the purpose of evading interference.

The general scheme of the Wirth torpedo is shown in Fig. 48. The diagram which is here presented in Fig. 49 shows the essential parts of the control system, and the circuit arrangements. The coherer 38, of the usual filings

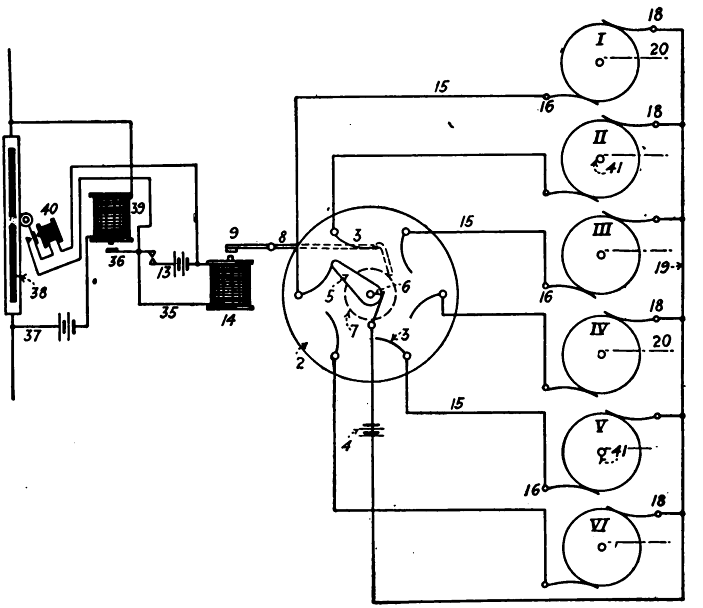

FIG. 49.

type, is connected in the circuit of the battery 37 and a sensitive relay 39. The armature of this relay, 36, serves to close a second circuit including the battery 13, by which the electromagnet 14 is operated. By means of the latter, there is operated the lever 8 which serves to rotate a ratchet wheel 7 by means of a pawl in the usual way, each time an impulse is received; at 40 is a tapper for the coherer. Arriving impulses cause the ratchet wheel to advance by one, two, three, etc.,

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teeth, and as the wheel is mounted integral with a contact disc, the latter is rotated at the same time. The fixed brush thus comes over a metal contactor or otherwise over the insulated part between the contacts according to the position of the ratchet wheel. Should there be a contact piece under the brush, the circuit of the battery 4 is closed and one of the six electric motors, I–VI is set in motion. By the rotation of the motor there is set working a spring contact device which will be further mentioned, and such contacts act to

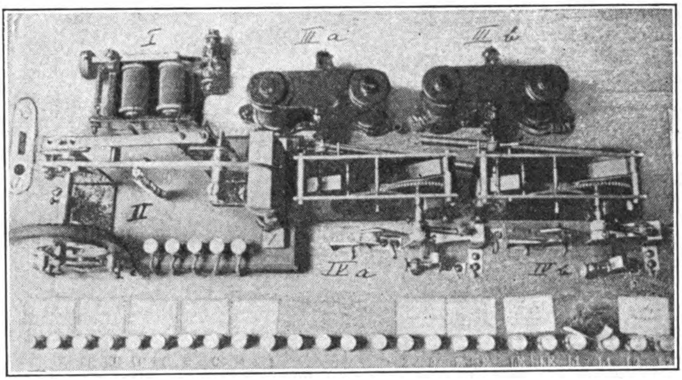

FIG. 50.

close the circuit of the apparatus which is to be finally worked, such as the movement of the rudder of the boat, etc. A second motor of the series serves to work another apparatus, and there is used one motor of small size for each operation to be carried out. The purpose of the motors is to furnish a time element device, which allows distinction between long and short impulses.

Fig. 50 shows the apparatus which is used for two distinct movements, namely, for steering to right or left. At I is a relay which is worked by the coherer, and at II the contact disc before mentioned. At IIIa and IIIb are two small electric motors for making the contacts, this latter

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being carried out by the spring contact devices IVa and IVb, one for each motor.

The coherer action sends current impulses by means of the relay I into the electromagnet of the contact disc. According to the number of impulses which are sent, we have the brush placed on a metal contact or in the insulated interval. When the brush is on one of the uneven-numbered contacts, the motor IIIa is set working, and it acts on the spring contact device IVa so as to operate the small contact switch noticed at the front. Such contact thus gives current for operating the movement of the rudder to the left by a suitable electromagnetic device. When the brush is on one of the even-numbered contacts the motor IIIb is set running, and it works the corresponding spring switch IVb so as to give current for a second magnetic device, for bringing the rudder to the right-hand side. The mechanism of the spring contact device is arranged on the retarding plan, so that it first sends out a wave signal which is received at the sending station; two seconds later it closes the switch.

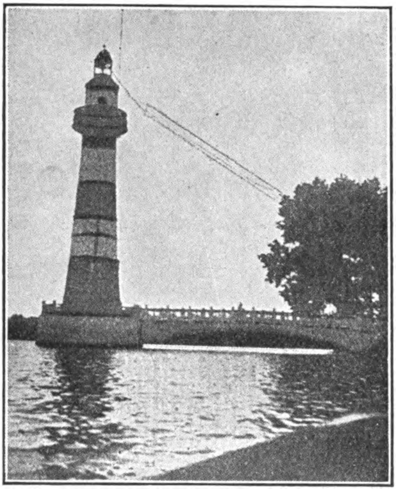

FIG. 51.

Should the brush remain but a short time on one of the contacts, this will give no effect, as the motor takes a certain time to start up, and thus the motor gives a method of working by means of long contacts, but not by short ones.

When the brush is on an insulated part of the disc the device is inactive, and the rudder comes automatically to the

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zero or central position. The signal which is sent back to the shore station is seen on the paper strip of the receiver, and the operator thus has a check on the working of the apparatus, and can correct any wrong working by subsequent signals. Wirth's transmitting antenna is shown in Fig. 51.

Dr. E. Branley's Control System

Dr. Branley, of Paris, in addition to various other kinds of distant control apparatus, devised an instrument with the

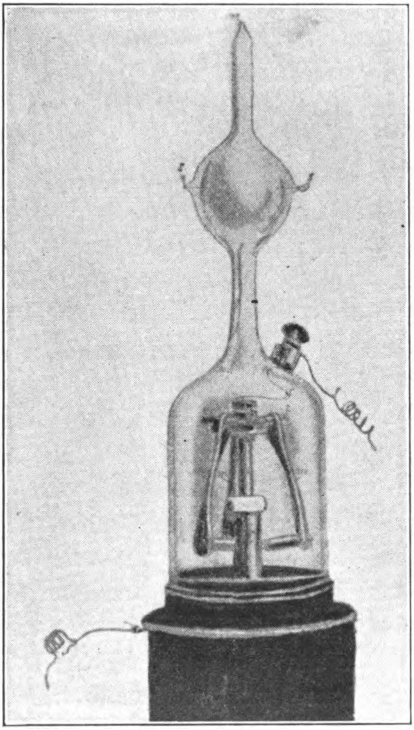

FIG. 52.

purpose of protecting the receiver against a continuous stream of sparks such as the enemy might send out in time of war.

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This, like a previous system of Fessenden's, utilizes breaks in a continuous emission of energy as the signal or controlling impulses, instead of "makes," with periods of rest intervening. If interfering signals are sent continuously the apparatus cannot be operated by any other signals, even from the controlling station, but should the interfering signals cease for a short time, the controlling operator can perform the desired operation by making the required number of breaks in his own continuous stream of signals.

Dr. Branley's protective device consists of a horizontal disc moved by clockwork, and is kept constantly in rotation first to the right, then to the left, by electromagnets which are acted on by distant waves. The rotation of the disc causes a series of contacts for closing different circuits corresponding to the different operations to be performed. The whole is so arranged that when a continuous stream of energy is received the disc rotates forward and back. If the disturbing signals cease for a brief period of time the control operator sends a code signal, which acts upon the disc and its contacts in such a way that the operation is performed.

In the present type of apparatus the waves are received upon a new type of coherer which is shown in Fig. 52. It is a modified form of Dr. Branley's tripod coherer, and is made up of a polished steel cylinder at the lowest part. It is fitted on an upright support, and from this three arms hang down by means of pivots. The arms carry well-rounded steel projections which bear lightly on the cylinder so as to make the coherer contact. The whole is enclosed in a vacuum chamber in order to protect the coherer from the action of the air. Such a coherer is useless when subject to vibration.

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CHAPTER XIV

WORK OF THE HAMMOND RADIO RESEARCH LABORATORY

Following the rotary switch scheme of Tesla, John Hays Hammond, Jr., head of the Hammond Radio Research Laboratory at Gloucester, Mass., began his experiments in the summer of 1910. No detailed accounts of these first experiments are available, as no systematic method of keeping records of the work had then been inaugurated, but it is known that mechanisms designed to steer a small boat were operated at a distance of three or four hundred feet. This apparatus, however, was never actually used in a boat for steering purposes.

During the following winter an entirely new set of control apparatus was designed in New York from Mr. Hammond's plans. The object in view was to build a control apparatus, which could be attached to existing automobile torpedoes. The coherer receiving set, relays, rotary switch, cut-off and center-stop mechanism, and batteries, were all contained in a brass tube about one foot in diameter and six feet long.

This apparatus was set up on a float landing about a thousand feet from the transmitting station. An antenna 15 feet high and 20 feet long was improvised, and after much careful adjustment, signals were received which were capable of starting, stopping or reversing the steering motor. The transmitting antenna was of the inverted L-type, about 80 feet high and 200 feet long. An antenna current of about 2 amperes was registered. The transmitting set was of the Clapp-Eastham type, 60 cycle, 3 kw.

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After these preliminary tests the apparatus was set up in a 12-foot gasoline launch, with a 15-foot antenna supported by bamboo poles. Considerable trouble was experienced in these tests. Due to the engine vibration, the sensitiveness of the Seimmans and Halske relay, as well as the Marconi coherers had to be greatly reduced. The Hertzian and inductive effects from the gas engine caused considerable trouble until the engine pit was entirely encased in sheet iron; this, however, did not eliminate the coherer trouble although it decreased it. The instruments were almost inaccessible for adjustment; the moist, salt air made matters still worse by corroding the multitude of contacts. Finally a determined attempt at rudder operation was made even though the action of the apparatus was far from what had been expected, and indeed necessary. The motor in the tube was accordingly connected to the boat's steering post by chain and sprockets, but when the current was switched on the motor was found to possess less than half the power required in turning the rudder hard over when the boat was under way. Three weeks were spent in futile attempts to eliminate the difficulties; then the tube and most of its contents were relegated to what was then the scrap heap, and now the historical collection.

Simplified Apparatus

Plans were at once formulated for the construction of much simplified apparatus, which could be thoroughly tested under conditions in which it could be protected from the weather, and observed and adjusted while in operation. An old house boat of about eight tons displacement fulfilled all the requirements for a floating laboratory splendidly. She was fitted with a gasoline engine capable of driving her four knots an hour, and forty-foot masts for supporting the antenna. This boat is shown in Fig. 53.

Coherers and relays of highest sensitiveness combined with

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the necessary ruggedness were secured from the electrical instrument makers in America and Europe. A steering motor of increased size was procured and mechanically connected to the steering wheel on the house boat by a worm-wheel reduction gear; a hand-operated clutch permitted either radio or manual control of the wheel.

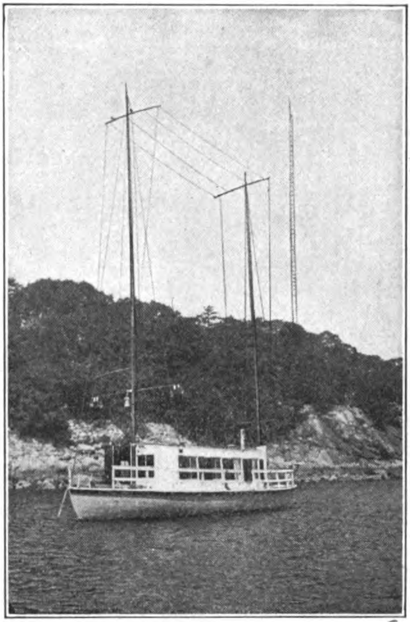

FIG. 53.

With this new apparatus installed in the *Pioneer* (as the house boat was afterwards named), where it was protected from the weather in an atmosphere that could be kept dry and warm by a coal stove, and arranged for continual observation and adjustment while in operation, the results were more satisfactory. The filings coherer, however, continued to be the chief source of our difficulties. Every known remedy for the trouble was applied to increase the sensitiveness and reliability, but despite all these, the sheet iron protection from stray Hertzian and inductive effects, the protective resistances and capacities for preventing sudden rise of potential at current-breaking points, — despite the care exercised in the selection and adjustment of jiggers, relays, decoherers, etc., — the results were so discouraging that it was decided to discontinue the use of the filings coherer, and adopt the Lodge-Muirhead mercury-steel-disc coherer. Several complete receivers of this type, which had been dis-

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carded from actual service, were purchased from the United States Navy. These had become obsolete and useless because of the advent of the telephone receiving sets. The best of these was installed on the *Pioneer* and was found to be more sensitive and reliable than the filings coherer. Fig. 54 shows this receiver as installed aboard the house boat and Fig. 55 is a detail drawing of the Lodge-Muirhead coherer.

After this change had been made the boat could be kept under fairly good control at distances up to and over a mile. It was steered over a prearranged course during both day

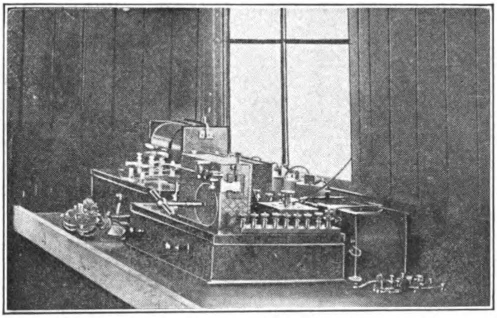

FIG. 54.

and night, and in all conditions of sea and weather. The course was by no means simple, covering, as it did, circles around several buoys, and a complete circle around the harbor. Fishing and other vessels were continually moving about the harbor but no great difficulty was experienced in avoiding them, and, at the same time, keeping on the course. It was found possible to steer the boat against either of several upright spar buoys a mile from the point of control. At night lights, automatically controlled by the steering mechanism, kept the "helmsman" at the transmitting key on shore informed of the boat's action. A white light would shine each time an impulse took effect; in this way the con-

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trol operator on shore was immediately informed if the receiving apparatus or part of the control apparatus had gotten out of order. As long as the rudder was in the central position no lights save the required running lights were burning. As soon, however, as the rudder moved to one side or the other a red or green light on the yard arm would be connected, depending on the resultant direction of the boat, and this would continue to burn so long as the direction of the steering motor's rotation was not reversed. When the rudder reached the extreme hard-over position an additional red or green light would flash, the two of the same color remaining illuminated while the boat was turning in her circle of shortest diameter. If the direction of motion was left then the two lights would be green in color; if right the color would be red. As soon as the rudder was again started back to the center the two lights would go out and a single light of the opposite color would come on; when the rudder was stopped at the mid-position by the automatic center-stop mechanism, the white light would again flash for an instant, signifying that fact.

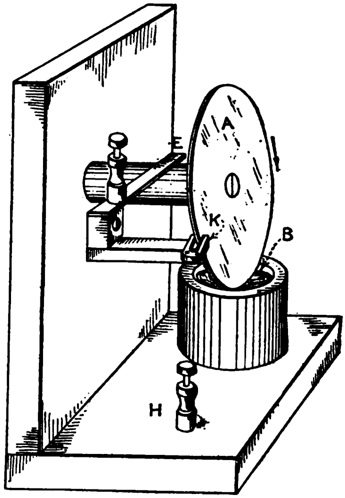

FIG. 55.
A is the steel disc with a polished knife-edge; B is the small cistern of mercury covered with a film of oil; K is a leather wiper; H and E are the terminals.

The steering of the boat was accomplished by sending Hertzian wave impulses, which, affecting suitable receiving and switching devices, controlled the one-fourth horse-power electric motor mechanically connected to the steering wheel.

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The rudder, by this means, could be made to move to port or starboard at will, or set at any intermediate position from the transmitting station.

During the next year some valuable additions were made for carrying on the experimental and research work; the size

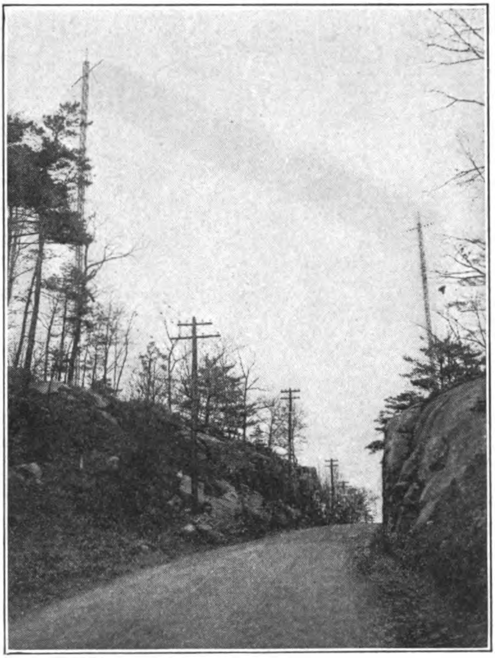

FIG. 56.

of the station was increased, two 330-foot towers (see Figs. 56 and 57) were erected for supporting the antenna, a battery of mercury-arc rectifiers was installed to furnish direct current for the operation of two 5-kw. 500-cycle motor generator sets, two 100,000-cycle alternators, a 24-inch searchlight, and various other apparatus. A 40-foot gasoline launch of 150 horsepower and over 25 knots was built for use as a torpedo, and

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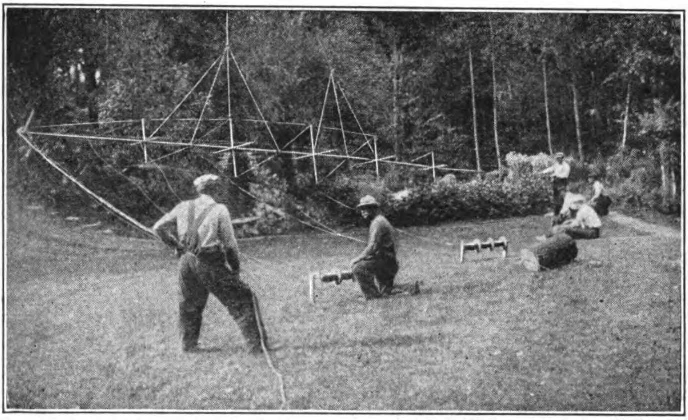

FIG. 57.
Installing the antenna system at the Hammond Station.

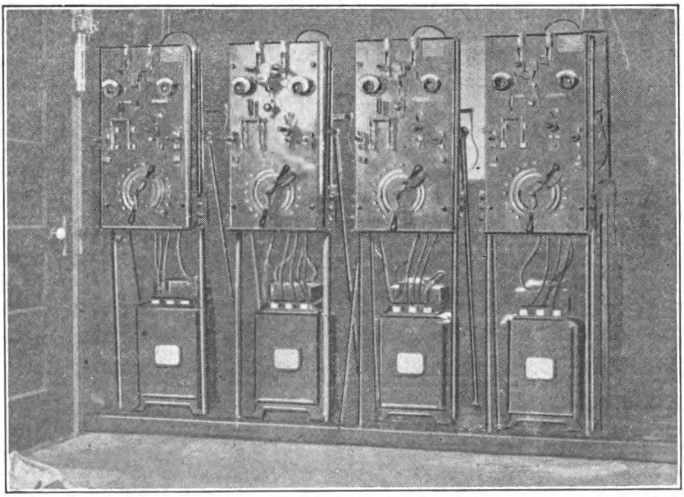

FIG. 58.

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other valuable additions were made to the control system, which permitted a greater range and more reliable operation. The battery of four General Electric 50-ampere rectifiers is shown in Fig. 58. Fig. 59 shows the 5-kw. Lowenstein Transmitter.

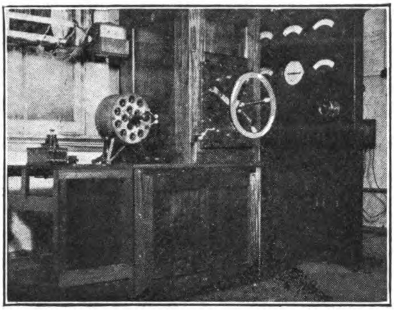

FIG. 59.

Steering Apparatus

A brief description of the control apparatus is here necessary in order to form a clear conception of some of the important details.

It has been previously mentioned that a control system is composed of two main parts: (1) the transmitter and receiver, and (2) the mechanism to be controlled. The principal parts of the mechanism, which is the rudder control apparatus, are the electromagnetically operated reversing switch, the steering motor, and the source of power.

The rotary switch, shown in Fig. 60, is essentially an insulating drum fitted with contact pieces; it can be revolved, step by step, through successive contact positions with a set of brushes by means of an electromagnet and pawl and ratchet. The contact positions and blank or "neutral" positions alternate; moreover, the contact positions are of two kinds, one for clockwise rotation of the motor, the other for counterclockwise rotation. The sequence of positions, then, as the electromagnet is impulsively operated, is port, neutral, starboard, neutral, port, neutral, and so on in the same order.

This is easily understood when the rotary switch is looked upon as a simple, double-pole, double-throw reversing switch connected to the armature of the steering motor, the shunt

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field of which is continuously excited. A diagram of this connection is shown in Fig. 61.

Consider the switch in the upper or neutral position, where the armature is disconnected from the source of power. There

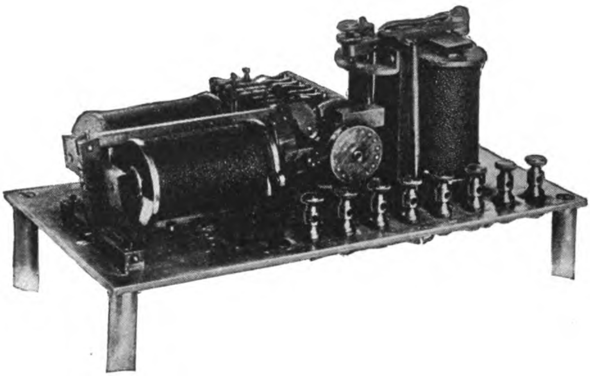

FIG. 60.

Electrically-operated rotary switch designed by the author and used in the Hammond System of control. Relay at right, drum switch in the center, and operating magnet at left. S

are two possible ways of closing the switch, corresponding to the two possible directions of motor rotation. One of these will, by swinging the rudder to port, cause the boat to steer around to port; the other will effect starboard motion. The only difference between these two reversing switches is that with the hand type, the motor after being stopped, can be made to run in the same direction again without the necessity of passing over the position for opposite rotation. With the rotary switch this cannot be accomplished unless some auxiliary instrument be used to prevent the motor's rotation while passing over the undesired position.

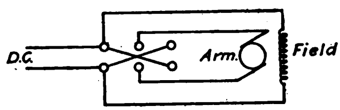

FIG. 61.

The steering motor should preferably be of the shunt type with the field winding continuously energized. This is important to secure quick action. Motors larger than one-fourth horse-power cannot well be used with such a controlling switch because the unregulated starting current becomes excessively large. Where greater power is required for rudder operation a pneumatic control apparatus is more effective. The one-fourth horse-power motor was found large enough for the 33-mile "Radio," which had a displacement of about four tons.

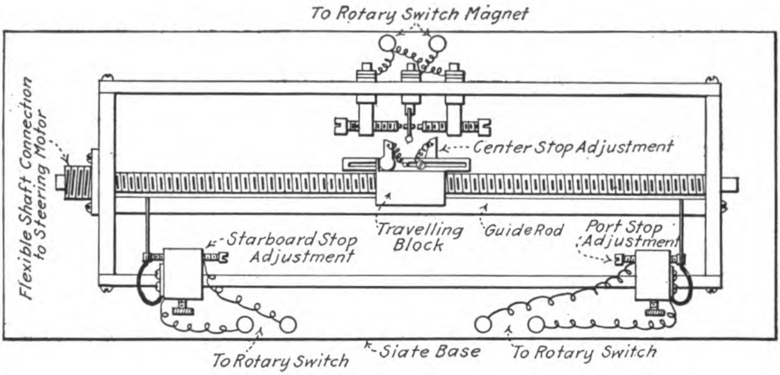

FIG. 62.

The source of power is preferably a storage battery. It should be of the most rugged type. An Edison 30-volt, 120-ampere hour battery gave excellent service in the Gloucester experiments.

A crude, but nevertheless operative, control system can be made up of these essential parts, since with them the steering motor, which is mechanically connected to the steering wheel, can be started, stopped, and reversed, the worm-wheel reduction gear serving to lock the wheel in any desired position after the power has been cut off from the motor. The value and reliability of such a crude controller, however, is much increased

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by the use of auxiliary instruments, which make it possible to greatly reduce the skill required of the controlling operator. The cut-off and center-stop mechanism is one of these. It consists essentially of a threaded shaft bearing a small traveling block, fitted with two fingers as shown in Fig. 62. This shaft is connected directly, or by means of a flexible shaft, to the reduced-speed shaft of the steering motor; near each end of the worm shaft is a platinum-tipped contact spring. At the center is a short stiff spring provided with a contact screw on each side.

The operation is as follows: The apparatus is so adjusted that the central position of the traveling block corresponds to the central position of the rudder, and the end contact springs are so placed that the operative leg of the motor circuit is broken by the motion of the traveling block when the rudder reaches the extreme right and left positions. The center-stop contacts are engaged by the fingers on the traveling block a short time before the rudder reaches the central position. By closing the circuit of the electromagnet which operates the rotary switch, these contacts make electrical connections which effect the turning of the drum to the neutral position, and thus stop the motor. The adjustment must be very carefully made in order to make the rudder stop at the exact position corresponding to straight-ahead motion of the boat.

Suppose the boat is steering ahead. An operator at the control station desiring to take control depresses his key once, the necessary length of the impulse transmitted being from one-half to one second. This impulse will move the drum to either a port or starboard position, and is sent in order to get his bearings. Let us assume that the boat immediately begins to swing to starboard. The steering motor has been energized and is swinging the rudder to the right. The time required for the rudder to move from the center to either extreme posi-

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tion is from five to fifteen seconds, depending on the speed of the steering motor. This time could be fixed at any value within these limits by adjustment of the field weakening rheostat connected in series with the motor's shunt field.

The operator, then, could allow the rudder to continue its motion to the extreme position, where it would be automatically stopped by the cut-off mechanism, or it could be stopped at any intermediate position, by sending another correctly-timed impulse after the first. This second impulse would simply turn the drum to the next neutral position and thus stop the motor. If he allowed the rudder to go to the extreme position the boat would travel in its circle of minimum diameter until the correct number of impulses were sent to change the rudder's position.

Since the drum was revolved to a starboard position by the first impulse, it remains there, the motor circuit for starboard rotation being opened by the cut-off mechanism. Obviously, then, two impulses are required to rotate the drum to the next port position. If these are sent, the motor will rotate in the opposite direction, and, if no more impulses are sent within the fixed time limit, the rudder will move to the central position and automatically stop. This central stop, as before explained, is effected by the automatic rotation of the drum to a neutral position. Remembering, then, that in this case the neutral position is followed by a starboard position, one impulse will send the boat to starboard again and the minimum number of impulses for port steering is three. If these are transmitted, the rudder will turn to the extreme port, unless stopped at some intermediate position, by sending an additional impulse.

It is thus seen that the nucleus of the apparatus is simply a wirelessly-operated switch, supplemented by auxiliary apparatus, which automatically perform operations that would be very difficult for the distant operator.

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In practice a difficulty developed which was only overcome after considerable experimentation. It was found that, when the rudder and traveling block were in their central positions, and three impulses were sent at the maximum speed permitted by the inertia of the various parts, the drum remained on the undesired contact long enough to allow a considerable number of revolutions of the steering motor in the direction opposite to that desired. The following would be the result:

The first impulse would effect rotation in the wrong direction, the motion of the traveling block being great enough to allow the contact finger to pass under the spring. The second impulse would bring the next blank space into position, stopping the block's motion; the third would effect the desired rudder motion and the block would immediately begin to move with the rudder in the desired direction. After a few revolutions, however, the center-stop finger would engage its contacts, and as a result the motor would stop.

In this way it was found impossible to get the rudder through the central position from one side to the other. Tests without the automatic stop, however, clearly indicated the futility of trying to dispose of it, — it being found impossible to steer a straight course because of the difficulty of stopping the rudder at the exact point necessary for steering directly ahead.

Attempts were made to surmount this difficulty by the introduction of considerable inertia into the rotating parts connected to the motor, so that in the brief interval of time necessary in passing over undesired operative positions of the rotary switch, the motor could not develop enough speed to cause the above-mentioned difficulty. This was partially satisfactory, but did not completely solve the problem.

The solution was finally found in a "time relay," especially built for this purpose after our plans, in New York. This instrument consists principally of an iron-clad solenoid with

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a movable core, and an adjustable air dash pot. A plan view of this relay is shown in Fig. 63.

When energized, the core is drawn up in a period of time that can be easily varied, by adjustment of a thumbscrew, from a fifth of a second to ten seconds. A set of heavy platinum contacts is fixed on the core and an adjustable screw so that a local circuit, carrying ten or fifteen amperes can be satisfactorily opened and closed at the end of the "in" stroke. A light spring serves quickly to bring the core back to the normal position after the solenoid is de-energized. This is facilitated

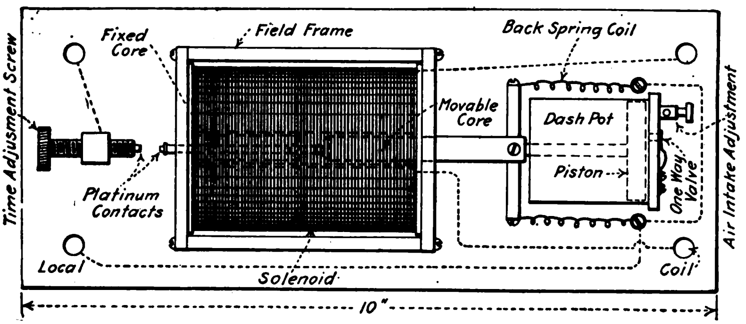

FIG. 63.

by a one-way valve which permits the expulsion of the air in the dash pot with but little retardation on the return stroke.

The solenoid windings were connected in parallel with the electromagnet of the rotary switch, and the contacts were connected in one leg of the battery circuit to the motor armature. By this means the motor armature current could not be exerted until a definite length of time had elapsed after the impulse had been sent, and thus the undesired operative positions on the drum switch could be passed over without difficulty. The time limit was usually set at about one second. Another time relay of the same kind was used for engine control. In this way short impulses of about one-

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half second duration were used for steering, and long impulses of about ten seconds were used for starting or stopping the engine. The engine control in these experiments was effected by opening or closing the ignition circuit, the engine being so adjusted that it would stop at the required point at which the explosions occur. It was found possible to start the engine in this way as long as an hour after it had been stopped. This second time relay was also used for firing ex-

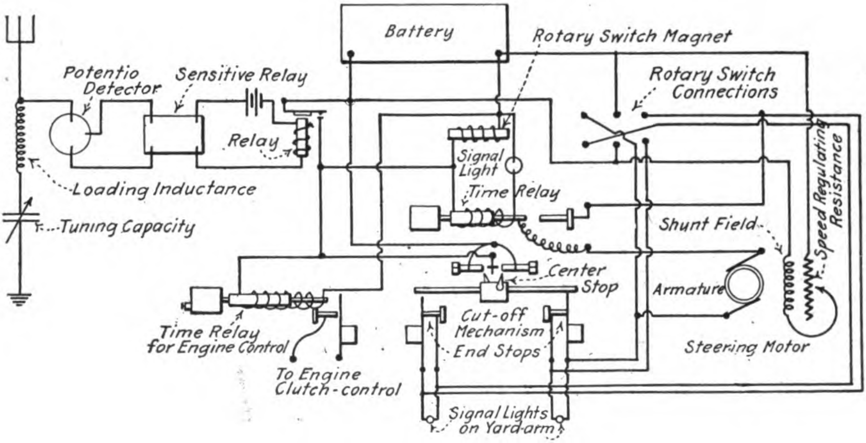

FIG. 64.

plosive charges of powder placed on top of the boat's cabin. The complete circuit is shown in Fig. 64.

During the summer and autumn of 1912, with this improved apparatus, the results were very encouraging. The 25-knot Radio of which Fig. 65 is a reproduction was controlled with reliability and precision at ranges of over three miles, a distance far in excess of that attained by European investigators. Demonstrations made before the U. S. War Department authorities proved beyond a doubt that the dirigible torpedo would be of great use in naval warfare, especially for coast defense.

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The operations can be carried on at night almost as well as by day. With a special reflector of the triple-mirror type, and a searchlight, the maneuvers of the boat can be followed with ease from the control point, although from any other position the reflected light, and the boat itself, are practically invisible.

The broad idea of the Hammond torpedo control system for coast defense is this:

One powerful transmitting station is employed and suitably placed in some protected situation with respect to the gunfire

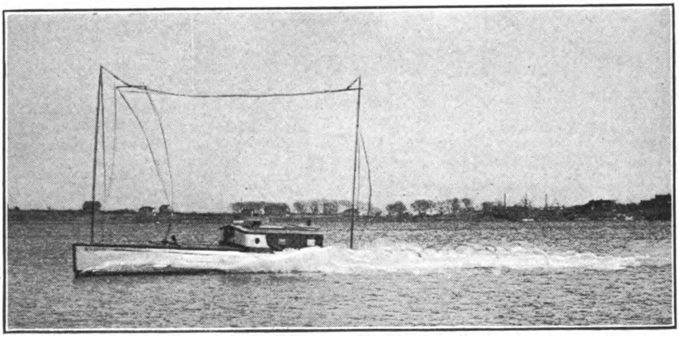

FIG. 65.

of the enemy. A number of operators are placed along the shore; these different operators have wire connection with the wireless station and telephone connection with one another. A number of torpedoes may be used, each of which is controlled by an impulse of specific characteristics. These are moored at a central protected torpedo base, and one or more can be controlled at the same time by either of the operators at the hidden control stations. The torpedoes are started at the base and passed on to the control of the operators in the most advantageous positions, who operate under orders transmitted over the telephone lines by the military

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head of the fortifications. The wireless station is equipped with a wave generator for each torpedo, and by means of the wire connections, which extend from the control point to the central station, impulses can be sent from either of these generators by either of the control operators.

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CHAPTER XV

THE SOLUTION OF THE PROBLEMS RELATED TO BATTLE-RANGE TORPEDO CONTROL

The problem of performing a number of operations aboard a moving vessel at distances of over a mile is by no means a

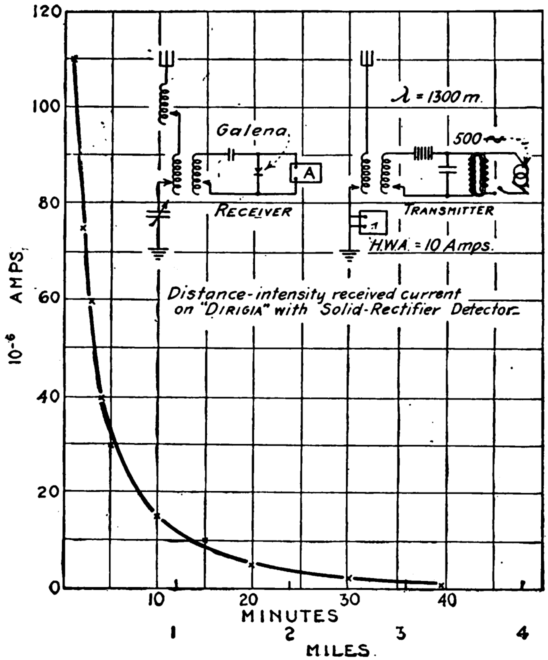

FIG. 66.

simple one, even from a theoretical point of view. It might be mentioned that controlling a number of mechanisms with but a single relay is easy in comparison with wirelessly con-

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trolling a relay five miles away, which at the same time is immune from accidental or intentional interference from other sources of energy. Then, too, when we reflect that probably less than one-billionth of the energy radiated into space by the transmitter reaches the receiver, the quantitative aspects of the problem begin to come into evidence.

Fig. 66 is a graphical representation of the current received on board the *Pioneer*, which was first used as a torpedo in the Gloucester experiments. The transmitting energy in the antenna * was about two kilowatts at a wave length of approximately 1300 meters. The group frequency was 1000 and, with the air cooled quenched spark gap, and loose inductive coupling between the open and closed oscillatory circuits, the decrement was fairly low.

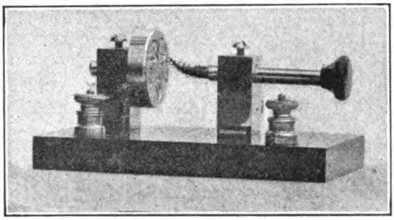

FIG. 67.

The receiving antenna as shown in the illustration of the *Pioneer* was of the inverted L type, 30 feet high and with a 20-foot flat top, the detector was one of the solid rectifier type, essentially a crystal of galena with a light spring contact. It is shown in Fig. 67 and was designed by the author. The current values given were read directly upon a Weston microammeter. The readings were taken at five-minute intervals, except in close proximity to the station, and the distances corresponding to these intervals were computed from the boat's speed and log readings. This curve shows how quickly the received current drops down within a mile, and how it remains almost constant after this distance is well passed. The high value of the received current within a short distance of the transmitter may be

* 300 ft. high, 400 ft. flat top.

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due to the augmentation of the Hertzian effects by the purely electrostatic effects, as evidenced by the curve made in the experiments with an electrostatic telegraph (Fig. 20). The received current at three miles was only about 3.10^{-6} amperes. So far as we were able to learn there was no relay, possessing the necessary mechanical and electrical stability, which was sensitive enough to operate reliably on such a small amount of energy. The most sensitive relay we could procure in the United States and Europe, which was rugged enough to operate reliably under the conditions of shock and vibration aboard a small high-speed boat in a rough sea, required about 300.10^{-6} amperes. We had as high a transmitting antenna as was practicable, the most efficient transmitting apparatus, and the most sensitive receiving set obtainable, and yet the breach between the available and the required received current was so wide that it appeared almost impossible to bridge it. With a sender that could deliver only one microampere at four miles, and a receiving relay that required 300 microamperes for operation, the problem was a serious and discouraging one.

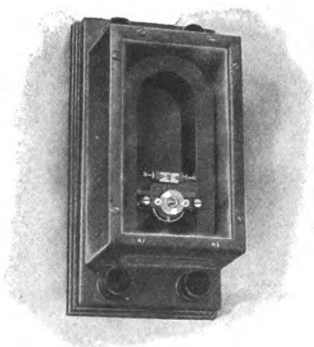

FIG. 68.

The first step in the solution was in the improvement of the sensitive relay. This was of the Weston pivoted galvanometer type, and is reproduced in Fig. 68 by the courtesy of the Weston Electrical Instrument Company. The permanent magnet was replaced by an electromagnet, which, by increasing the field intensity, more than doubled the sensitiveness. Fig. 69 shows graphically the effect of variation in the field energizing current. Later the author replaced the delicate platinum

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contacts by a single platinum point on the movable arm, and an adjustable globule of mercury. This increased the operating sensitiveness from twenty to thirty times, for only an extremely small contact pressure was required to keep the circuit closed under considerable vibration. These relay improvements therefore increased the receiver's sensitiveness about fifty times.

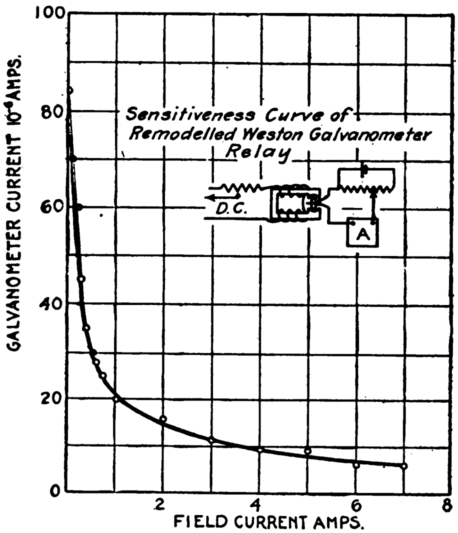

FIG. 69.

Fig. 70 is a plan view of this improved sensitive relay. T and T1 are terminals of electromagnet windings, W and W1, surrounding soft iron cores. When in operation T and T1 are connected to a source of direct current. T2 and T3 are terminals of movable coil C, the pivots and mountings of which are not shown. B is a light arm fixed to C. Terminal T4 is connected to arm B. L is a non-oxidizable contact piece fixed to B. M is the top of a column of mercury extending into and above the block H. The size of the globule

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M above H is adjustable by screw S. The distance of M from L in its normal inoperative position may be varied by the adjusting screw S1.

Ordinary instruments of this kind have permanent magnets, but by the use of electromagnets and suitably shaped pole pieces, a much more intense field, and consequently a greater sensitiveness, could be secured.

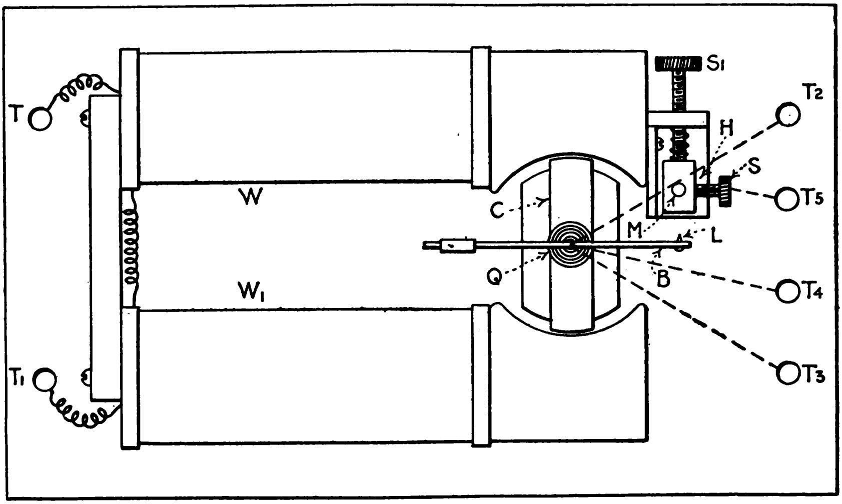

FIG. 70.

When C is energized by current flowing in the right direction, arm B carrying contact L will move toward M. L will make contact with and move into M and establish a good low-resistance connection in the local circuit connected to T4 and T5. When C is de-energized, the spiral spring Q causes B to return to the normal position. With a relay of this description currents of a few microamperes could be relayed under conditions of vibration which necessitated a current of a hundred microamperes with the best of ordinary sensitive relays of the solid contact type.

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The next step in the solution of the control problem was to discard the Lodge-Muirhead coherer, and to adopt the vacuum-tube rectifier, which was perfected in this country by DeForest. This is about twice as sensitive as the best solid or electrolytic rectifiers, and has the additional advantage of being more stable, both electrically and mechanically.

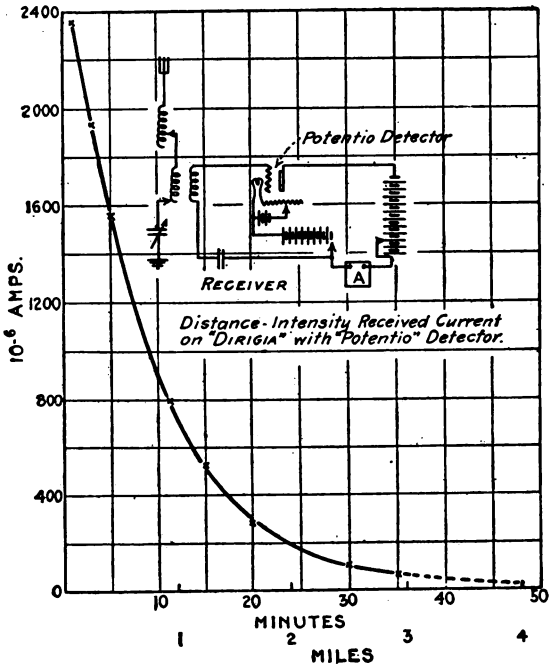

FIG. 71.

In attempting to improve this detector, the writer discovered a connection arrangement which made the detector a true potential-operated device. The other existing forms of vacuum detectors as well as the many forms of solid rectifiers, electrolytic, thermal, thermoelectric and other detectors are practically all conceded to be current operated, and because of this fact they not only consume energy, but also

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decrease the receiver's selectivity by increasing the damping of the receiving circuits. This change in the receiving circuit made the instrument approximately twenty-five times as sensitive for relay or indicating instrument operation; this can be readily observed from a comparison of Fig. 71 with Fig. 66. Both curves were made on the same trip, one going out to sea and the other returning, in order to insure the greatest possible similarity in the conditions. The transmitting energy was also kept constant, the only variable factor being the distance.

To prove that this circuit arrangement made the detector a potential operated device, four of these detector circuits, each with its separate indicating instrument, were arranged so that they could be simultaneously in connection with an antenna circuit tuned to distant signals. It was found that in no case was the signal intensity in the first set decreased by connecting on one or all of the other three. Moreover the signals in all four receivers were approximately equal. The slight inequalities were due to difference in sensitiveness of the separate detectors. The effect on a single indicator could be proportionally increased by connecting it to the secondary winding of a transformer, having separate primaries which were connected to the separate detectors. Theoretically this circuit furnishes a means of securing any received current desired, simply by connecting a sufficient number of units.

With these circuits the vacuum detector can be adjusted so that the paralyzing effect of strong signals is not encountered. This makes the detector electrically stable and is a very important feature. The detector can also be adjusted so that the local battery current, which we shall call the field current, increases or decreases as desired, when the signals arrive. We will not attempt to give a theoretical consideration of the detector's action, but simply explain the various circuits employed.

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Fig. 72 represents a vacuum tube detector, comprising exhausted glass bulb H, in which are fixed filament W, grid G, and plate F, the terminals of which are T, T1, T2, and T3. These terminals lead through H in the usual manner. F1, G1, and W1, show more clearly the shapes and relative sizes of the plate, grid, and filament, respectively.

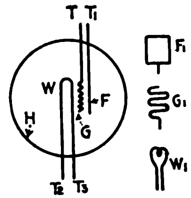

FIG. 72.

Fig. 73 is a diagrammatic representation of the author's circuit arrangement for use with the instrument shown in Fig. 72. When used in a circuit, such as that shown in Fig. 72, this vacuum tube is called a Potentio detector. That part of the diagram included in the circle J is the Potentio detector circuit, and the remainder is simply one of the large number of ways in which it may be applied in a radio receiving set.

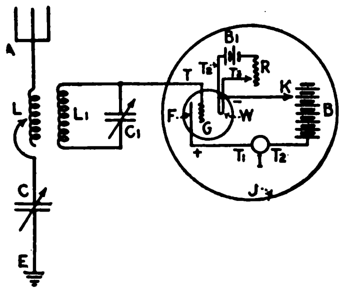

FIG. 73.

W is the hot wire filament, which is maintained at an incandescent temperature by the battery B1, the degree of incandescence being varied by resistance R. G is the grid, and F the plate or cold electrode, which is connected through the indicating instrument I, such as a telephone, to the positive pole of the battery B. This battery in practice consists of about thirty cells; it is connected to W through the variable connecting means K. The grid terminal T is connected to some point in the receiving circuit where the highest potentials are developed by the incoming waves.

In this receiving circuit A is the antenna, L the open circuit tuning and coupling inductance, C a variable tuning condenser, and E the earth connection. This open receiving

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circuit is coupled to the closed resonant circuit comprising inductance L1 and condenser C1.

Fig. 74 illustrates another type of receiving circuit employing the well-known Oudin resonator principle for increasing the potentials.

Fig. 75 illustrates a circuit arrangement and apparatus used in producing an indicated effect greater than can be obtained with one detector. With ordinary current-operated detectors only one can be used advantageously in a receiving circuit, since with a plurality of detectors requiring current energy for their operation, the energy of the incoming waves is

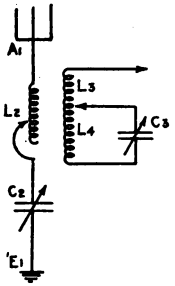

Fig. 74.

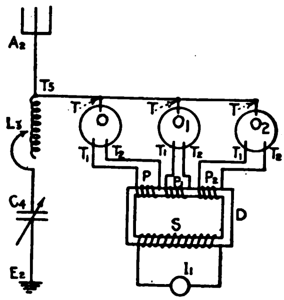

Fig. 75.

divided between the detectors, and consequently no increase in effect is obtainable. It is possible and advantageous, however, to connect a plurality of Potentio detectors to one antenna circuit, or circuits coupled to a single antenna, in order to obtain an indicated effect much greater than is possible with one Potentio or with other detectors.

In Fig. 75 the antenna A2, condenser C4, inductance L3, and earth E form the open receiving circuit. To a point of maximum potential, such as T5, is made a connection which leads to the grid terminals T of a plurality of Potentio circuits represented by O, O1, and O2. O, O1, and O2 are similar to that part of Fig. 73 included in the line J, with the exception

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that the primary windings P, P1, and P2 are used with O, O1, and O2 respectively instead of the indicator represented by I. D is the core of a transformer in which P, P1, and P2 are the primaries acting conjointly on secondary S. The latter as shown is connected to indicating instrument I1. This obviously receives the effects of O, O1, and O2 combined when the receiving circuit A2, L5, C4, E2 is energized by received currents.

Fig. 76 is the cascade circuit for amplification. In this circuit arrangement the received energy develops potentials in L6

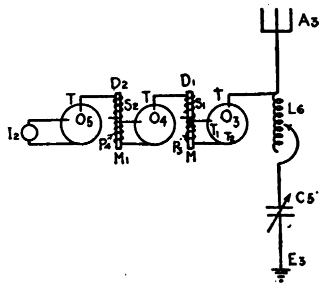

FIG. 76.

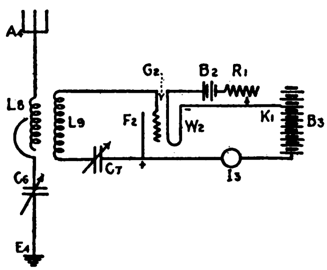

FIG. 77.

which so influence the Potentio detector O3 as to cause variations in the battery current flowing through P3. The variations of current in P3 induce corresponding variations in the secondary winding S1. These are of higher potential and in turn effect the induction of currents of still higher potential in S2. The final effects at the indicator I2 are thus increased considerably over the initial effects.

Fig. 77 represents an adaptation of the Potentio circuit which has been found especially valuable for the operation of indicators of the galvanometer type. Experimental results prove it to give indicated effects on galvanometers 25 times as great as those obtainable under similar conditions with solid rectifiers and other well-known detectors of equal

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sensitiveness. No improvement, however, is noted in telephone operation.

The antenna circuit comprising antenna A4, inductance coil L8, condenser C6, and earth E4, is coupled to the coil L9 by means of L8. The condenser C7 must be connected in the circuit as shown in order to secure the greatly increased effect not noticeable with other detectors or circuit arrangements.

In practice B3 and R1 are adjusted until the desired indication is secured at I3, care being taken that the applied voltage at B3 is not too high. By experiment the adjustment should be made so that a decrease in the normal current occurs when the signal arrives. Then by varying the capacity of C7 while signal impulses are arriving the indications at I3 may be made to remain during and *after* the actuating signal has ceased. The length of this time of indication after the signal has ceased can be increased or diminished by variation of the capacity C7. With C7 short circuited or with the connection to C7 broken the effects at I are very much less, so that it can be readily understood that the presence of C7 between the cold electrode and the end of L9 not connected to G1 fulfills the condition necessary for obtaining the desired operation.

There is no danger of burning out I3 by the action of excessively strong signals, since with signals above a certain intensity value, the current in I3 will remain at zero. The normal field current is diminished by the incoming signals in proportion to the strength of these signals. This is another important feature.

The Potentio detector stood up very well under the very severe conditions. It must be remembered, as is shown by the received current curve (Fig. 71), that the detector must be rugged enough to remain in perfect adjustment under the strongest signals received within a few hundred feet of the

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transmitter, and at the same time it must be sensitive enough to operate the relay at the extreme range of eight miles. It must be capable of performing these functions for hours at a time, perfectly, without a single hitch, or the necessity of adjustment. The strongest signals in our experiments invariably caused the familiar "blue arc" between the plate and filament, with the usual forms of connection with this type of detector. This necessitates opening and reclosing of the field battery circuit to restore the normal condition of sensitiveness.

With the Potentio this is impossible. The blue arc is caused by too great a density in the ionic field current. There is a critical value which varies for different bulbs depending on the degree of exhaustion and the distances between the plate and filament. It is only necessary to bring the field current to the critical value either by increase in the field battery voltage, or by superimposing the currents arising from incoming signals upon the normal battery current through the ionic field, to start the arc.

It is possible to obviate this trouble, but only at the expense of sensitiveness. The most sensitive adjustment is obtained when the field current is just below the critical point. If the incandescence of the filament or the voltage of the field battery is reduced sufficiently, the normal field current can be made so low that the strongest incoming oscillations will not cause a sufficient superimposition of current to bring its value up to the critical point. But the cost of this freedom from arcing is a great reduction in sensitiveness.

The adjustment of the Potentio is such that the normal field current is safely enough below the critical value to allow for increases due to occasional vibrations of the plate and filament, which reduce the distance between them, and yet high enough to insure good sensitiveness. Instead of in-

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creasing the field current the received oscillations decrease its value. The strongest signals, instead of causing the blue arc, can only bring the field current down to zero from its normal value. Thus it is seen that the signal effect of the Potentio is a change in the normal current, — a change which decreases its value away from instead of towards the critical point; that instead of producing excessively strong indicator operating currents with excessively strong signals, the Potentio automatically prevents such an effect by ceasing to furnish an increase in field current change when signals increase above a certain critical value.

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CHAPTER XVI

THE DIFFICULTIES ENCOUNTERED IN PROVIDING PROTECTION FROM INTERFERENCE

The selectivity problem, which is by far the greatest of all difficulties to be overcome in the successful evolution of a wirelessly controlled torpedo, is one of comparative difficulty, depending upon the degree of non-interferability desired. A selective receiver is like a safety vault. The operator at the transmitter may be likened to the owner of a safe who alone possesses the combination. No safes are absolutely burglar proof, and their value depends principally on the length of time required for a skilled cracksman to reach the inside. Likewise no receivers are absolutely selective for the simple reason that an operator bent on interfering can take observations and measurements on the signals sent out to the selective receiver (just as the burglar may watch the opening of a safe by the owner), and adjust his own apparatus to emit waves of exactly the same characteristics as those of the transmitter designed or adjusted for the selective receiver's operation. The burglar, instead of trying to learn the combination, may use sheer force in reaching the inside of the safe. In the same manner a hostile transmitting station can perform the desired effect in the selective receiver, *i.e.*, operate the receiving indicator or relay, by the emission of very strong signals so that forced oscillations are set up. This is known as the "whip crack" effect, and it is believed that very few receivers are immune from it.

The best wireless signaling sets, such as those used by the U. S. Navy are considered very selective, and yet the inter-

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ference existent between them is very serious. Take, for example: Washington (Fig. 78) is receiving a message from the Eiffel tower station in Paris, which is sending at 3000 meters wave length. It is easily possible for a station in California, with an equal amount of power, and at practically the same distance, to make the Paris message unintelligible at Washington, simply by sending signals at or within, say, two or three per cent of 3000 meters wave length.

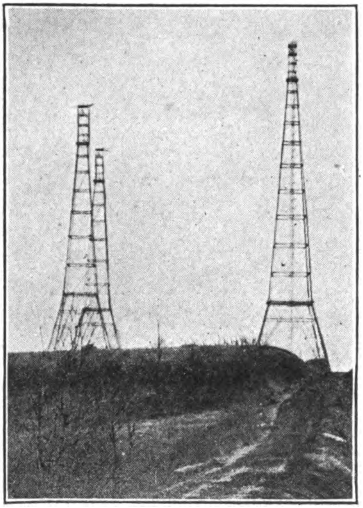

FIG. 78.
Towers of the U. S. Naval Station at Arlington, Va.

Again, some insignificant station with little power within a few miles of Washington could make it practically impossible for them to receive any messages at all from distant stations by sending out broadly tuned signals of high damping. These highly damped, or untuned signals, by the previously mentioned whip crack effect, cause the receiving antennæ to vibrate in their own periods, and thereby produce a great deal of interference.

To illustrate: Sing a clear, steady tone into a piano. The string, which when struck emits that tone, will audibly vibrate in resonance. Then shout loud and gruffly into the same piano; practically every string will be set in vibration, producing a dull roar. The first tone corresponds to the signals sent out by a tuned transmitter; the second (noise) to the whip crack signals emitted by an untuned transmitter.

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Another comparison might serve to illustrate the degree of selectivity necessary for torpedo control. We have three persons A, B, and C. A and B are together at one place, and C is, say, a mile away. The problem is to allow A to hear what C says while B is shouting in his ear. Impossible, you say? Yet the torpedo problem is practically an exact analogy. We must be able to make the electromagnetic ear of the torpedo hear our control impulses eight miles away while it

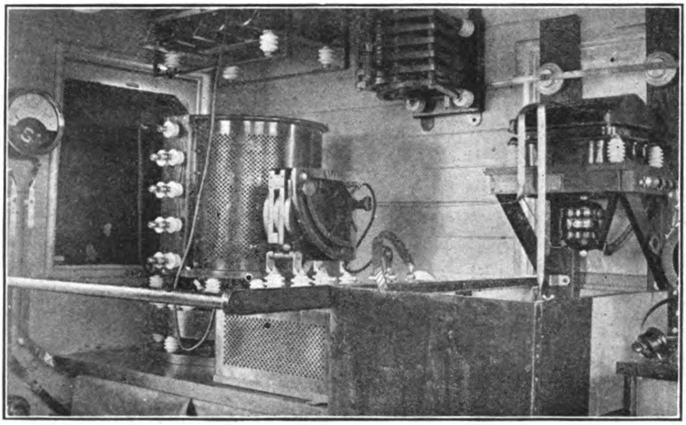

FIG. 79.
Transmitter of Telefunken 5 kw. set aboard U. S. S. South Carolina.

is at the very side of a battleship capable of almost deafening it with the force of its own powerful signals.

It is true that we could sidetrack the real problem, and simply use such a large amount of energy at our shore station, that more energy could be delivered to the torpedo at eight miles than the hostile battleship could deliver at a hundred feet. This is possible because the amount of energy that can be efficiently used aboard a modern battleship does not greatly exceed 5 kw. Such a 5 kw. set is shown in Figs. 79 and 80. This is due to the limited size of the antenna. A shore station, with practically no limits on the size and height of its antenna,

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can easily use 100 kw. The shore station also has the advantage of being able to direct its energy somewhat in the general direction of operations. This can be accomplished either by the use of an inverted L-type antenna, with a flat top long in proportion to its height, as suggested by Marconi, or by means of the Bellini-Tosi Radiogoniometer.

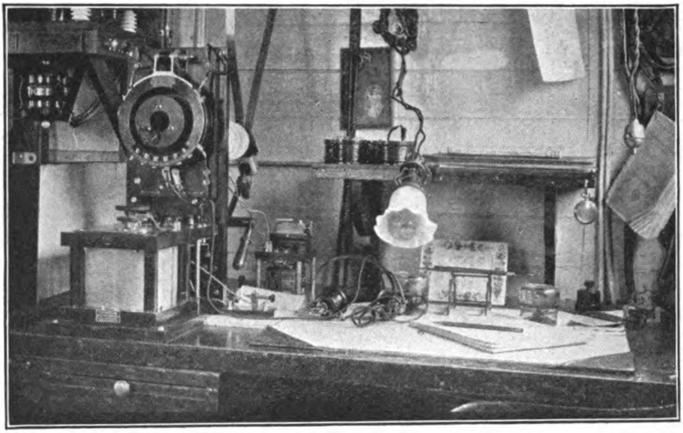

FIG. 80.
Receiving set aboard U. S. S. South Carolina.

Sidetracking the real problem by using a land station of tremendous power is, however, not the practical and efficient solution. In the first place, although desirable, absolute selectivity is not necessary. A receiver that will require, say, fifteen minutes time for the enemy to learn its combination, will, in all probablity, satisfy the requirements.

We have described the systems used by the principal investigators abroad; those who have observed closely will have seen at once that not one of these systems is immune to intentional interference for the simple reason that no provision is made for avoiding the broadly tuned or whipcrack signals, that may be sent out by any transmitter.

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What use, we may then ask, and well, are the various types of codal selectors and protective devices, when any hostile battleship can absolutely lock the receiving apparatus so that not even the controlling operator can get in a signal, by the simple process known to operators as "sitting on the key."

Systems like those of Anders Bull, Walter, Branley, and others, providing complicated apparatus, aside from not being able to cope with interference, actually defeat their own end by their very presence; designed to increase the reliability of operation, they diminish it by increasing the number of mechanisms, especially those electrically operated, which are likely to get out of order.

The keynote of success in developing mechanisms that must operate without adjustment is simplicity. The simplest form of distributor that will accomplish the end in view, namely, to close any one of a number of circuits, is all that is necessary and indeed is to be greatly preferred. Wirth's apparatus which provides means of changing the receiver's wave length, is somewhat nearer the solution, but it, like the others, provides no means of getting away from *forced* oscillation effects; any system that does not do this is useless for torpedo control.

The selectivity problem cannot be solved by any form of codal selector or protective device inserted in the receiving circuits *after* the relay; they must be placed *before* the relay, that is, they must protect *it* from interference if they are to serve their purpose. Instruments like the resonance relays and monotelephone amplifiers have this protection inherently by virtue of their vibratory elements tuned to the spark frequency of the transmitter, but these, as pointed out elsewhere, are subject to vibration, shocks, and sounds.

In order to reach the solution we must devise systems that not only have a high degree of selectivity for tuned signals,

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but also provide means of evading the whip crack effects of broadly tuned or plain-aerial transmitters.

Interference preventers have been invented, which, to a large extent, prevent disturbances from untuned transmitters of whip crack signals. At Washington, in 1910, the writer witnessed government tests of such a receiver, worked out by Fessenden. Reception of signals from a station about 400 miles away, at Brant Rock, Mass., was carried on while a five-kilowatt station less than a mile away was sending interfering signals. The wave lengths of the two transmitters were different by only a few per cent. Fig. 81 is a diagram of this receiver. The relation between the two sets of coils is such that when the same current passes through the two primaries, no current is induced in the secondary circuit, the two secondary inductances, L1 and L2 being wound in opposition. By tuning each circuit separately to the incoming signals, and then throwing one of them slightly out of tune, the broadly tuned and whip crack signals will divide equally between the two primaries, while the tuned signals will be received by one side alone, their strength undiminished by the presence of the other circuit to ground.

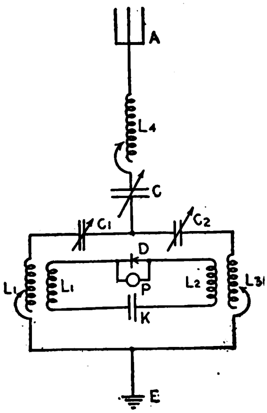

FIG. 81.

When such a receiver is used in conjunction with a transmitter of the undamped, continuous wave type, like the high frequency alternator, or the Duddell-Thompson arc, a very considerable degree of freedom from interference is possible for acoustic signaling.

Whether such a system is selective enough for torpedo control depends upon the effectiveness of two possible methods of producing interference. One is, to listen for the controlling

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impulses, measure their wave length, and then adjust their own transmitter to send out similar signals. Whether or not they can do this in the time necessary for the torpedo to reach them (probably ten minutes), is not known. Since probably not more than twenty-five short course-correcting impulses are necessary to guide the torpedo to a target to a distance of, say, six miles, it is a matter of conjecture. The other interference method is to use one of the siren interference machines invented in Germany. It consists essentially of a set of rotating switches, which automatically, and in rapid succession, cause a series of sharply tuned waves of gradually increasing length to be emitted. This, however, as an interference device, has the disadvantage that the available power is divided among the different wave lengths used.

Assume that the energy is 5 kw., and that we use 20 separate wave lengths. The energy on each wave length (not taking into consideration the difference in efficiency with change in wave length) is one-twentieth of the total or one-fourth kilowatt. For telephone operation this would not apply, since that instrument would give the full indication during the short time that the particular wave length affecting it was being emitted, and thus make reception of other signals impossible; but for relay operation unless the separate wave lengths were each emitted for a time equal to the mechanical vibration period of the relay's movable element, or longer, the effect would be equivalent to the effect of a one-fourth kilowatt transmitter in continuous operation on the correct wave length. Even though the rotating switches were rotated at a speed slow enough to cause a closure of the relay each time the correct wave length was emitted, the fact that nineteen other similar wave lengths must be sent out in succession, each for the same length of time, makes the interfering impulses so far between that corrections can be made from the control station.

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The second method, even with the limitations explained, is probably the better of the two methods, as the shore station could send out confusing or blind signals differing in wave length from the steering impulses, so that the enemy afloat would have no means of determining which was actually the correct one.

In order to increase the selectivity of torpedo operation to such a point where interference is much more impractical, Mr. Hammond and the writer worked out a number of Selective control systems. Of these only a few will be described. Since the work done along this line at the Hammond Radio Research Laboratory is practically the only work of this kind in the United States, and since nothing new is forthcoming from European inventors, these selective systems represent the latest improvement along this line.

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CHAPTER XVII

A MEANS OF OBTAINING SELECTIVITY

Selective Transmitter-Receiver Unit.—Fig. 82 illustrates a type of transmitter-receiver unit suggested by the writer in 1911. H.F.A. is a high-frequency alternator, or other high-frequency current producer, which supplies energy to L1 through interrupters I1, I2, and key K.

The principle applied in this selectivity scheme is the same as that brought forward by Blondel in his spark-tuned re-

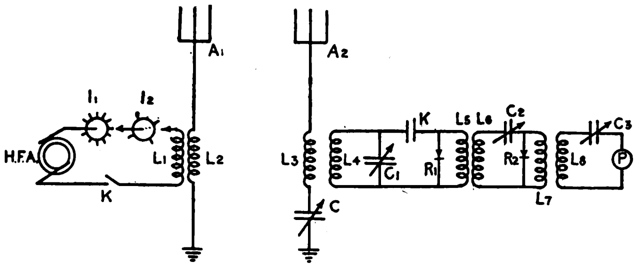

Fig. 82.

ceiver some time ago, but it has the additional selectivity of one or more other circuits, besides the high-frequency and spark-tuned circuits. Moreover, this other circuit, which is tuned to an intermediate frequency between the two mentioned at the transmitter, has an inaudible periodicity, so that the signals cannot be heard at all by an ordinary receiver. The wave length of this inaudible frequency is so far above the wave lengths used in signaling that the ordinary receiving circuits will not respond to it, and so far below that of the spark-tuned circuits that they would give no indication even if the frequency were audible.

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Supposing the stiffness of the receiving circuits is such as to require twenty impressed oscillations to swing them up to full amplitude, then the ratio of the different frequencies at the transmitter should be 20 to 1, that is, the transmitter emits several frequencies, all in the same wave, the values of which drop down in steps according to the ratio 20 to 1 or the ratio found most suitable.

Consider the wave length of the emitted waves to be 1000 meters. The oscillation frequency corresponding to that value is 300,000 per second. The oscillation frequency at H.F.A. would then be 300,000. Allowing 20 oscillations to

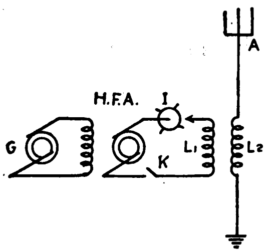

FIG. 83.

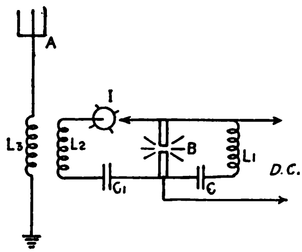

FIG. 84.

the wave train, the interrupter I1 would have a frequency of 15,000 per second. That is, at each contact of I1, 20 complete oscillations from H.F.A. would occur in L1 and be radiated from A. Dividing 15,000 by 20 we have 750, the frequency of interrupter I2. When key K is closed antenna A then radiates electric waves of 1000 meters length, which are broken up into an inaudible group frequency by I1. This resultant signal is then broken up into a frequency of a lower order, determined by the speed of I2.

Figs. 83 and 84 show two other ways of obtaining the same results as with Fig. 82. In Fig. 83 G is an alternating-current generator having a periodicity of about 7500 cycles, which excites the field windings of high-frequency alternator H.F.A.,

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the latter being rotated at such speed as to give a 300,000-cycle current. The current delivered by H.F.A. will then have a periodic amplitude variation of a frequency corresponding to G, namely 15,000. H.F.A. delivers this periodically varying 300,000-cycle current through interrupter I and key K, to antenna A by means of the inductively coupled coils, L1 and L2.

When interrupter I is stationary or short circuited, antenna A radiates electric waves of 1000 meters length at an amplitude frequency of 15,000, which being above the audible limit, will not be heard by a spark receiving set. If I is rotating so as to give 750 contacts per second, A will radiate this wave of two periodic characteristics at a rate of 750 per second, which of course is audible. Thus in Fig. 83 G takes the place of I1, in Fig. 82, for producing the 15,000 per second group frequency.

Fig. 84 shows another method of producing a high-frequency current having two or more group frequencies within or out of the range of audibility. B is an arc oscillatory-current generator of the Duddell-Thompson type, fed from a source of direct current. In shunt around the arc is a condenser, C1, inductance, L2, and interrupter, I.

Consider I as being short circuited and circuit B–C–L1 open, then as is well known in the art, when B, C1, and L2 are properly adjusted, oscillatory currents will be generated in the circuit B–C1–L2, the frequency of the alternating currents developed being dependent principally on the values of C1 and L2. Now if circuit B–C–L1 be closed oscillations will be generated in it of, say, 7500 cycles. This has the effect of producing a 7500 cycle amplitude variation of the current of the circuit B–C1–L2 and antenna A being in resonance with B–C1–L2, will radiate electric waves of 300,000 oscillatory frequency, and at a group frequency of 15,000 impulses per second.

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Now if interrupter I, giving 750 contacts per second, be included in the circuit B–C1–L2, the radiated waves will be broken up into the audible frequency of 750 per second.

The receiving circuits, as shown in Fig. 82, are tuned to the oscillatory current frequency, the inaudible amplitude frequency, and the audible group frequency. Antenna circuit A2–L3–C and circuit L4–C1 are both tuned to the transmitter oscillation frequency. By the action of rectifier R1, L5 receives unidirectional currents from L4–C1, thereby energizing circuit L6–L7–C2, which is in resonance with the frequency produced by the interrupter giving 15,000 contacts

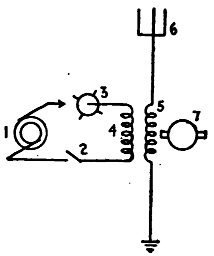

Fig. 85.

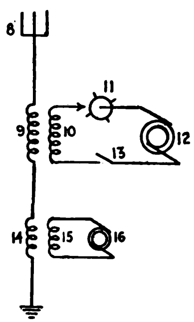

Fig. 86.

per second. If I2 of Fig. 82 is in operation, circuit L8–C3–P will then be energized, and telegraphic signals may be produced at P by the transmitting key K.

Figs. 85 and 86 show two other methods of producing the ultra audible group frequencies of the high-frequency currents. In Fig. 85, I is a high-frequency alternator supplying current to antenna 6 through interrupter 3 and key 2, and coupling coils 4 and 5. Motor 7 is mechanically connected to coil 5 and rotates it in such a way as to produce a periodic amplitude variation, the frequency of which is ultra-audible.

In Fig. 86, antenna 8 is inductively connected to high-frequency alternator 12 and ultra-audible frequency alter-

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nator 16 by means of coupling coils 9 and 10, and 14 and 15 respectively. An interrupter 11 and key 13 are in circuit with 12.

When the transmitter is in operation, 11 interrupts the current from 12 at an audible rate, and by the action of 16, the amplitude of the antenna current is varied periodically, the periodicity being dependent upon the frequency of 16.

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CHAPTER XVIII

NATURE OF INDICATOR CURRENTS IN RADIO RECEIVERS

The absolute necessity for a simple and effective interference preventer for our torpedo control system led the author, in the fall of 1912, to investigate the nature of the phenomenon accompanying the reception and indication of alternating-current waves of radio lengths.

Prof. G. W. Pierce, of Harvard University, has already done considerable work along this line, and in his book on the "Principles of Wireless Telegraphy" are found the results of his extensive researches on detectors and rectification phenomena, together with hypotheses based on them. Although Professor Pierce's work has been mainly along the line of determining the cause of rectification in radio detectors, he also presents brief but concise discussions on the nature of the received currents in the indicator circuit.

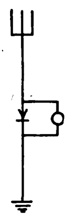

Fig. 87.

On pages 173–174, explaining the action of solid rectifiers in a receiving circuit like that shown in Fig. 87, he says:

"A train of incoming waves produces an alternating e.m.f. in the antenna circuit. This e.m.f., when in one direction, produces a large current through the detector, charging the antenna. When the e.m.f. reverses the current from the antenna to the ground through the carborundum is smaller, thus leaving the antenna charged with a small quantity of electricity. The effect of the whole train of waves is additive, so that this charge on the antenna is cumulative. The accumulated charge on the antenna escapes through the

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telephone shunted about the carborundum, causing the diaphragm to move. Each subsequent train of waves causes a similar motion of the diaphragm, which is evidenced as a note in the telephone, equal in pitch with the train frequency of the waves.

"It is immaterial whether the detector permits the larger current to flow upward, charging the antenna positively, or permits the larger current to flow in the downward direction, charging the antenna negatively. The explanation is the same in both cases.

"With very slight change this explanation can be made to apply also to those cases in which the detector is in a condenser circuit coupled inductively or directly with the antenna circuit."

Such a modification consists essentially in substituting the stopping condenser for the capacity, and the coupling coil for the inductance of the antenna. That the two circuits are of the same type is seen by an inspection of Figs. 87 and 88. In both cases the detector has the alternating e.m.f. impressed upon it and, as Dr. Pierce told the author personally, the charge accumulates in the stopping condenser, and discharges through the indicator at a rate equal to the transmitter's group frequency, and in exactly the same manner as in the previously mentioned circuit.

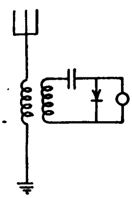

FIG. 88.

The best value for the stopping capacity, if this be true, would be such that with signals of medium intensity, it would be completely charged by one wave train. The resistance of the receiving telephone also influences their best value, and must be taken into consideration.

The application of such an explanation to relay operation is, however, of principal interest to us. There is no reason why the theory applied to arriving wave trains of 1000 per

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second frequency should not hold equally well for trains of much greater length, provided the stopping condenser is large enough to absorb all the energy delivered by the rectifier during that longer train. Neither is there any reason apparent why wave trains composed of equal amplitude oscillations should not act in the same way as do the damped trains.

Granting these suppositions, we could use undamped oscillations in trains of any length, and a stopping condenser sufficiently large to absorb all the energy supplied to it during that time by the detector. At the end of the wave train then the accumulated charge in the condenser would discharge through the relay with much greater effect than could be obtained with short successive wave trains. Experiments based on these suppositions were performed, but no increased relay deflections could be obtained.

In a sketch of the action of wireless telephonic apparatus, on page 305 of his book, Dr. Pierce says:

"The receiving apparatus is identical with that employed in wireless telegraphy, and makes use of a receiving antenna coupled with a circuit containing some type of rectifying detector; *e.g.*, an electrolytic detector, a crystal contact detector, or a vacuum tube rectifier. About the detector is shunted a sensitive telephone receiver.

"The action is as follows: If an unmodified train of electric waves having a frequency higher than the limit of human audibility (35,000 vibrations per second) arrives at the receiving station, the receiving circuit, if properly tuned, will sustain electric oscillations which, passing through the detector, will be rectified and will give a series of rectified impulses to the receiving telephone circuit.

"These impulses, being all in one direction, will act as a continuous pull on the diaphragm, — a continuous pull for the reason that the diaphragm cannot follow the rapid successive impulses, and because also, *on account of the inductance*

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of the telephone circuit these impulses are modified electrically into practically continuous current through the receiver."

An application of this explanation for a receiver which discriminates between spark and undamped wave signals for relay operation at once suggests itself. If the inductance of the telephone or relay is high enough to smooth the high-frequency direct-current impulses into a practically continuous current, the indicator current, then, with unbroken, undamped oscillations, is practically unvarying and unidirectional. For spark signals or chopped continuous wave signals of audible frequencies, the high-frequency direct-current impulses are modified into one impulse the length of the train, but the self-inductance of the indicator is insufficient to appreciably affect these longer train-length impulses, so that they pass through unmodified. However, by inserting a choke coil of large value, the broken signals may be greatly reduced in intensity, while the unbroken signals remain practically the same as before, except for a decrease in amplitude due to the added ohmic resistance of the choke coil. A selective receiver based on this principle will be described in a subsequent chapter.

That these two explanations do not agree is evident, but it is difficult to understand why the action for continuous waves should be other than the action for damped trains of waves.

In November of 1912 the writer performed some experiments in the effort to verify either of Pierce's theories, or to unearth the true explanation of the nature of the received current in the indicator circuit. These experiments, although crude and incomplete seem to shed new light upon this little investigated phenomenon.

The writer presents the data and conclusions derived from these tests in the hope that they may incite further investigation.

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Experimental Determination of the Nature of the Indicator-operating Currents in a Radio Receiver

Fig. 89 shows diagrammatically the connections and arrangement of apparatus, and the following table gives data relative to the apparatus used.

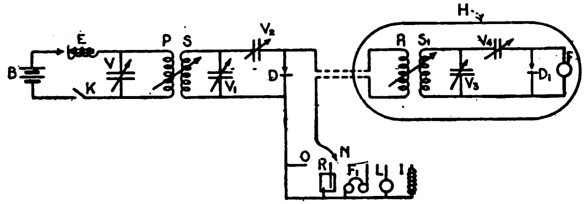

FIG. 89.

B.........Storage battery.
E.........Ericcson test buzzer.
K.........Key.
V.........Murdock variable condenser (max. cap. 0.002 mfd.) set at 100°
V1........Murdock variable condenser (max. cap. 0.002 mfd.) set at 120°
V2........Murdock variable condenser (max. cap. 0.002 mfd.) set at 45°
V3........Murdock variable condenser (max. cap. 0.002 mfd.) set at 60°
V4........Murdock variable condenser (max. cap. 0.002 mfd.) set at 180°
P.........Primary Murdock inductive tuner 69 turns.
P1........Primary Murdock inductive tuner 72 turns.
S.........Secondary Murdock inductive tuner, contact stud No. 2.
S1........Secondary Murdock inductive tuner, contact stud No. 3.
D.........Iron pyrite detector.
D1........Iron pyrite detector.
F.........3000-ohm Schmidt-Wilkes telephone receiver.
R.........Weston relay (microammeter movement).
F1........300-ohm Marconi wavemeter phone.
L.........2500-ohm, 8-c. p., carbon filament lamp.
I.........2500-ohm (d. c.) No. 34 copper wire coils (2) on a laminated wire core.
H.........Distance of apparatus in circle from remainder, 10 feet.

Experiments and Observations

With the apparatus arranged and adjusted as shown and in operation, the following experiments and observations were made:

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1. Test for tuning: With the coupling between the coils of the two tuners moderately weak (secondaries about three-fourths the way out of primaries), the tuning was fairly sharp, the point of maximum signal intensity being capable of determination to within 1 or 2 degrees on either of the variable tuning condensers, V, V1, or V3.

2. To prove that tertiary circuit, S1–V3, does not receive its energy direct from primary exciting circuit, V–P, instead of from the rectifier D, as intended: Signals in F were diminished to inaudibility by variation of V1.

3. Test for difference in energy between secondary (S–V1), and tertiary (S1–V3) circuits: F connected across D, with P1 disconnected, indicated a signal that was only slightly greater than at D1.

4. With D elements out of contact, it was found necessary to change V1 to 60 degrees for resonance, but signals at F were very sharply tuned and much stronger.

5. R, F1, L, and I were separately thrown in circuit with D and P1 with the following results at F, the signal intensities being in the order given.

1	O.	No great difference between the intensities; signals moderately strong.
2	R.	
3	F1.	
4	L.	
5	I.	Signals very weak.

6. All apparatus included by circle H was replaced by a closely coupled set of coils on a laminated core, a variable condenser, and a telephone, all comprising a low-frequency oscillatory circuit of such wave length as to respond to the group frequency of the buzzer signals. (See Fig. 90.) The signals at F2 were considerably reduced with this arrangement, but fairly good spark tuning could be secured.

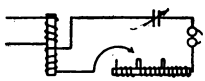

FIG. 90.

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7. Change of detectors at D: Detectors of various types, such as the different forms of the vacuum tube rectifier, carborundum, and electrolytic, were used at D with practically no change in results, save that in some instances the signals through the whole series of tests were stronger or weaker due to differences in detector sensitiveness.

Conclusions Drawn from Tests

The very fact that energy in the form of tuned high-frequency oscillatory currents is developed in the tertiary circuit is a proof that the effect of a train of waves is *not additive;* that the whole train of waves does not pass through the indicator as a single pulse in one direction, but that each separate impulse in the train passes through the indicator without losing its distinctness, and is not smoothed down into one impulse with the others in the train. The fact that this tertiary circuit was 10 feet distant from the other circuits, and the fact that when the audions were used as detectors, the signals at F could be cut out completely by de-energizing the filament, show conclusively that the currents in the tertiary circuit were not set up by direct induction from the primary exciting circuit, and that therefore they were due to the "blow excitation" of the distinct high-frequency direct-current impulses arriving from D, the rectifier. The fact that there was tuning, and that the selectivity was so good that the signals at F could be rendered inaudible by variation of V1, also strongly support this proof.

The fact that the signals at F were very nearly as strong as when F was connected across D, indicates that the rectified high-frequency impulses were not flattened greatly, due to inductive resistance, as otherwise the energy delivered by D1 to F could not have been so great, and the tuning would not have been so good.

With D out of contact the result was simply to connect V2

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in parallel with V1, P1 being in this connecting line, the wave length being thereby increased so that it was necessary to decrease V1 to 60 degrees in order to restore resonance conditions; the current in P1 was therefore alternating instead of pulsating direct, and maximum value instead of half value, due to the chopping off action of the rectifier. The signals at F were, therefore, much stronger.

The fact that there was no very noticeable decrease in signal intensity when N was changed successively from O to R, F, and L, apparently indicates two things, namely: (1) the resistance of the detector D was very high, for additional resistances up to 2500 ohms in its circuit with P did not greatly change the total resistance of the circuit, since by their addition the signals were not greatly diminished; and (2), coils of wire wound on magnetized or permanent magnet cores present little inductive resistance to high-frequency pulsating currents. (The coil of the Weston relay R surrounds a core magnetized by the permanent magnet of the instrument; the coils of the Marconi phone, F1, are wound on permanent magnet poles.)

When I, the coils of copper wire inductively wound on a laminated core, having a resistance equal to that of the lamp, L, was connected, the signals became very nearly inaudible. This shows that inductances with soft, laminated iron cores present a relatively high inductive resistance to high-frequency pulsating currents. Since these coils had considerable distributed capacity it is believed the weak signals that were heard were due to the conductive effects of this capacity.

The intensity of the signals was decreased to this great extent, because the high-inductive resistance of I obliterated the separate pulses in the train, and lumped them into one unidirectional-current impulse the length of the train, which, having a very low frequency, could not swing up circuit S1–V into resonant operation; the detector D1 and tele-

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phone F, therefore received no energy, and so no signals were heard.

That this lumping action does occur was shown with the low-frequency tuned circuit, which responded to the group frequency of these impulses. The reduction in intensity of the received current at F_2 in this low-frequency circuit was due to the fact that with the apparatus at hand, a high resistance was inevitable in order to secure the inductance necessary for obtaining the long wave length required in that circuit.

The tests with different detectors show that all give practically the same effects.

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CHAPTER XIX

THE INTERFERENCE PREVENTER

The writer devised this receiver in order to utilize fundamental principles relating to the flow of direct and alternating currents for the production of a highly selective radio system.

These properties have been applied in wire telephony, and kindred branches of the electrical arts, and, more specifically, deal with electrical circuits and their properties. These properties may be so varied as to make the circuit conductive to currents of constant value, while greatly resisting the flow of varying currents, and vice versa. In other words, by inserting an electrostatic condenser in a metallic circuit connected to a source of alternating potentials, an alternating current would flow, but the same circuit would present an infinitely high resistance to the flow of a direct current. Also by inserting a coil of high self-inductance in a metallic circuit connected to a source of direct unvarying currents, the resistance to direct currents would be low, while the same circuit would greatly impede the flow of an alternating or varying current, the extent of the impedance depending upon the inductance of the coil, the limits between which the amplitude of the current varies, and the frequency of the alternations or variations.

In radio signaling systems of today two principal kinds of electric wave producers are in general use. The older of these is the spark system, with which electromagnetic waves are generated by the spark discharge of a condenser. The waves are sent out in groups, the group frequency being de-

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pendent upon the frequency of the alternating current charging the condenser, and the spark-gap setting, and the length of the waves upon the electrical sizes of the condenser, and the inductance through which it discharges.

The number of waves in a train is governed by the damping of the circuit, which, in turn, depends on the various sources of energy loss, such as heating, and radiation of electromagnetic waves.

For example, take a 500-cycle transmitter emitting a 1000-meter wave. The 500-cycle alternator is connected to the condenser circuit through a step-up transformer. The condenser is charged during the first half of each alternation of the primary current and discharges across the spark gap when its potential reaches the necessary value. This discharge occurs at the peak of the alternating-current wave in the primary circuit, is oscillatory in nature, and the number of oscillations in the train is dependent upon the damping. If the damping is small 15 oscillations may occur in the decadent train before the potential drops too low to overcome the resistance of the spark gap.

The time during which the discharge takes place, therefore, with a 1000-meter wave (300,000 frequency), and 15 complete cycles to the train, would be $\frac{15}{150,000}$ of a second, or one ten-thousandth of a second. Thus with the 500-cycle, 1000-meter wave transmitter, once in each one-thousandth of a second the condenser discharges for one ten-thousandth of a second, producing a decadent train of, say, 15 oscillations.

The other type of transmitter is the continuous wave generator, which either by the high-frequency alternator or the Duddell-Thompson arc, produces continuous undamped waves. The waves, instead of being produced in decadent trains during only one-tenth of the time, as with the spark sets, are generated continuously and with constant amplitude.

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At the receiving station the effects produced by the two types of wave generators is somewhat different.

With the spark set the oscillatory currents developed in the receiving antennæ by the transmitter, and built up by resonance are rectified, and flow through the indicating instrument. The telephone, which is used as the indicating instrument, therefore receives a direct-current impulse for each discharge of the transmitting condenser. These impulses, although consisting of a number of separate impulses, act as one pull on the telephone diaphragm, which vibrates at a rate of 1000 times per second, corresponding to the transmitting group frequency. This periodic motion produces an acoustic note of high pitch. Dots and dashes are distinguished by the length of time during which the note is produced, dots, say, one-tenth second, and dashes one-fifth to one-half second. This note is produced in the receiving telephone only when the transmitting key is closed.

With the undamped wave transmitter there is no audible variation in the received rectified current, the effect of which is practically the same as that of a continuous direct current in the receiving telephone. Therefore a continuous pull on the diaphragm results so long as the sending key is depressed.

This, then, is the essential difference, from a low-frequency consideration, between the effects of spark transmitters and undamped wave transmitters. The former produces a periodic received current, while the latter produces a constant received current.

At present radio stations using these different systems produce considerable mutual interference. By the use of suitable apparatus we may differentiate between the two kinds of effects at the receiving station, and thereby secure a greater degree of selectivity.

The following description covers methods for accomplishing the desired results, with particular reference to the circuit arrangements illustrated by the drawings. Figs. 91, 92 and 93 show graphically three common types of radio transmitters.

Fig. 91 illustrates a spark transmitting set. The alternating-current generator G supplies current to primary P of step-up transformer T, through the controlling key K. Secondary S supplies high potential current for charging condenser C, to break down the spark gap SG. When the potential reaches the sparking value, C discharges across SG, and through inductance L, and by electromagnetic induction and resonance, an oscillatory current is set up in the radiating system composed of antenna A, inductance L1, and earth E.

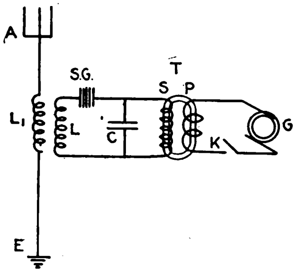

FIG. 91.

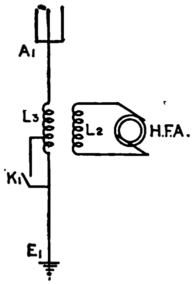

FIG. 92.

In Fig. 92 a continuous wave transmitter is shown. High-frequency alternator, H.F.A., sets antenna A1 into electrical vibration by means of coupling coils L2 and L3, as is common in the art. The antenna is earthed at E, and signals are sent by making a condition of resonance or dissonance between H.F.A. and the tuned radiating system A1–L3–E1. This is accomplished by short-circuiting or otherwise changing the inductance or capacity of the radiating system with the transmitter key in such a manner as to produce the desired signal. In this way the signals may consist either of periods of work or of rest of the radiator.

Fig. 93 illustrates an undamped wave transmitter, based

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on the principles of the Duddell-Thompson oscillatory arc. The direct-current generator G1, which preferably gives a potential of about 500 volts, supplies direct current to the electrodes of the arc AR, through the choke coils L4 and L5. When properly adjusted, electric oscillations are set up in the closed oscillatory circuit, comprising arc AR, condenser C1, and inductance coil L6, the frequency of which is determined principally by the values of C1 and L6. By electromagnetic induction and resonance oscillatory currents are produced in the radiating system composed of antenna A2, inductance L7, and earth E2. In order to send signals, the key K2, which establishes resonance, is used.

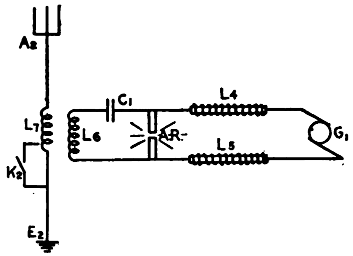

Fig. 93.

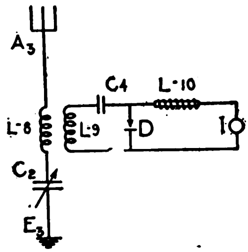

Fig. 94.

Figs. 94, 95 and 96 are schematic representations of receivers based on the idea of reducing interference between spark and undamped wave systems.

Fig. 94 illustrates the circuit arrangements of a receiver for use with an undamped wave transmitter, such as Fig. 92 or 93.

The action is as follows: By the phenomenon of electric wave propagation and reception, when the transmitting key is closed, alternating currents of high frequency are developed in the resonant receiving antenna system, which includes antenna A3, inductance L8, condenser C2, and earth E3. Circuit L9-C4-D is energized, and current energy is sup-

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plied to detector D, through the stopping condenser C4. D is a detector such as a thermal or thermoelectric; L10 is a choke coil, and I an indicating instrument for translating the received currents into effects observable with one or more of the physical senses. D produces a unidirectional current in the circuit D–L10–I, for each wave train impressed upon it. That is, for signals from a 500-cycle spark transmitter, D produces a pulsating, unidirectional current in the indicating circuit, the frequency of which is 1000 per second, equal to the transmitting group frequency, and for signals from an undamped-wave transmitter. D produces a unidirectional, unvarying current in the indicator circuit. Therefore it is obvious that the distinguishing difference between spark and undamped-wave signals is that one produces a periodic received current, while the other produces a constant received current. The detector D, it must be understood, has too much inertia to follow the high-frequency impulses of the oscillatory current, which are of the order of 500,000 per second, but it can and does follow the impulses corresponding to the group frequency, which need not be greater than 1000 per second. This inertia or lagging action is due to the fact that detectors of this class which are operated by the heat developed by the incoming oscillations, cannot heat and cool with sufficient rapidity to follow the enormously high number of periodic variations in the heat-producing current.

Referring now to Fig. 94, choke coil L10 is of such value as to greatly impede the flow of the periodically varying currents produced by spark transmitters, while direct currents set up by continuous wave transmitters flow unimpeded. For this reason the interfering effect of a near-by spark station on a continuous wave receiving station is greatly reduced.

Fig. 95 illustrates another method of securing the same freedom from disturbance. The receiving antenna system, composed of A4, L11, C5, and E4 is coupled to the closed

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oscillatory circuit, comprising L12 and C6, with which it is in resonance. Circuit L12–C6 supplies oscillatory-current energy to detector D1, which furnishes unidirectional current to winding W of indicating the instrument and to primary P1 of transformer T1. Secondary S1 is connected to winding W1 through stopping condenser C8, and rectifier D2 rectifies the alternating current supplied by S1 for use at W1.

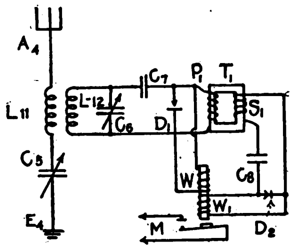

FIG. 95.

The indicating instrument is here represented as a relay in which M is the moving element, but any other form of indicating instrument may be used, or W and W1 may be independent primaries of an induction coil, both of which, when in operation, produce equal and opposite effects upon a secondary coil, connected to the indicating instrument, while one, operating alone, produces the signal effect.

The operation is as follows: When continuous wave signals are received, D1 supplies unidirectional currents to W and P1. There is no induction of current into S1, because the currents in P1 do not vary, and therefore only W of I1 is energized, and M is attracted, *i.e.*, the relay is operated.

If periodic currents are delivered by D1, such as are set up by spark transmitters, currents are induced in S1 and therefore W1 receives direct-current impulses by the action of D2 and C8. Now T1, W, and W1 are so proportioned that with spark signals of the common frequencies, the magnetic effects of W and W1 are equal and opposite. M will, therefore, be unaffected when group-frequency signals are received, but will operate without difficulty with continuous wave signals.

Fig. 96 represents the circuit arrangements and apparatus necessary to prevent interference from continuous wave

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transmitters to receivers of spark signals, such as are produced by the transmitters of Fig. 91. Antenna A6, inductance L16, condenser C12, and earth E6, form the receiving antenna circuit. Coupled to this is the closed circuit composed of inductance L17 and capacity C13. The two circuits are tuned to resonance with each other and with the transmitter. When energized, L17–C13 supplies energy to detector D4, through stopping condenser C14. D4 delivers unidirectional currents to primary P2 of transformer T2. Secondary S2 is connected to telephone F2. The continuous currents produced in the circuit D4–P2 by continuous wave transmitters produce no induced currents in S2. Therefore F2 does not operate when continuous wave signals are received. Spark signals, however, produce periodic direct currents in P2, which by induction produce alternating currents in S2 and F2. F2 therefore receives spark signals without difficulty, but remains inoperative for continuous wave signals.

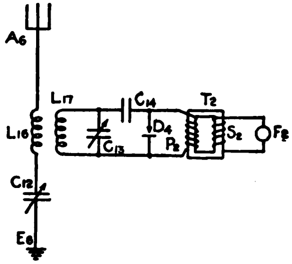

Fig. 96.

Fig. 97 is a schematic representation of a thermal detector circuit. D is the fine wire of the thermal detector, which is connected in series with choke coil L18, indicating instrument I2, and a source of direct current Z, which is a battery and potentiometer.

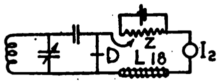

Fig. 97.

This circuit is suitable for use with the antenna circuit shown in Fig. 94 for the continuous wave receiver.

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CHAPTER XX

DETECTORS

According to the definition adopted by the standardization committee of the Institute of Radio Engineers, a radio detector is "that portion of the receiving apparatus which, connected to a circuit carrying currents of radio frequency, and in conjunction with a self-contained or separate indicator, translates the radio-frequency energy into a form suitable for the operation of the indicator. This translation may be effected either by the conversion of the radio-frequency energy, or by means of the control of local energy by the energy received."

A wrong impression relative to the exact function of a detector in a wireless receiver has been prevalent among those engaged in radio work. This misconception, as pointed out by Professor Pierce, is that detectors are more sensitive to electrical energy than the telephone, galvanometer, or relay is.

Detectors are necessary only because the energy of the high-frequency received current is in an unsuitable form for use with the indicating instruments employed. This is obvious when we consider such instruments as the Hetrodyne receiver of Fessenden's, which is an indicator so arranged that the high-frequency currents themselves operate it — no detector or translating device of any kind being required.

Because the frequency of the oscillations is so high (of the order of a million per second), the moving coils of galvanometers, the diaphragms of telephones, or even the light fiber of the Einthoven string galvanometer cannot follow them. No motion, and consequently no indication therefore results.

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The energy must be applied either in such a form that it acts in one direction on the indicator, as required in the telephone and galvanometer, or, if alternately in opposite directions, the frequency of the alternations must be so low that the inertia of the moving parts of the indicator does not come greatly into play. In the case of the telephone this frequency should not exceed 2000 per second, about 1000 per second being the best value; with the Einthoven string galvanometer the best frequency is still lower, in the neighborhood of 100 per second; coil galvanometers have such a slow period, about 1 to 10 seconds, that they, for all practical purposes, are beyond consideration in this respect.

True, alternating-current instruments depending on the Thompson effect have been constructed, which give unidirectional deflections for alternating currents of radio frequency, and, like the Hetrodyne receiver, do not require a detector, but they are so insensitive that they can be used only where comparatively large energies are received, such as in the wave-meter application by Dr. Seibt.*

For the operation, then, of our common and most sensitive indicators, we require some form of translating device; this is not, as has been supposed, for the reason that the detector is a wonderfully sensitive instrument, but because it furnishes a means of utilizing the marvelous sensitiveness of these indicators.

Taken singly the detector is perhaps the most important part of a radiodynamic system. It is to the torpedo what the ear is to a telephone operator; all orders are received through it; without it wirelessly directed torpedoes would be impossible, just as the telephone would be impossible without human ears. It is delicate, necessarily, because of the slight effects it must respond to; like the human ear it must be

* Elihu Thompson, Elec. World, May 28, 1887; see also Proceedings Inst. Radio Engineers, Vol. 1, Part 3, 1913; and Phys. Review, Vol. 20, p. 226, 1905.

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able to stand up under heavy cannonading as well as to hear weak signals from a distance; it must be rugged to withstand the severe conditions imposed; rugged, because subject to strong effects, both mechanical and electrical, which tend to break down its original sensitive adjustment; rugged for the reason that the possibility of readjustment in a dirigible torpedo is excluded.

An ideal detector is one that is extremely sensitive, and at the same time immune to disturbances which make readjustment a necessity; one that will operate with the faintest signals, as well as stand up under the strongest electrical and mechanical shocks.

Although close approaches have been made to this ideal, the perfect detector has not yet been produced. Those in use purely for signaling, *i.e.*, radiotelegraphy and telephony, where an operator is constantly in attendance, are near enough for all practical purposes, but for such work as torpedo control, they are not yet what they should be. Even though the best, namely, those designed or modified especially for this purpose, do operate perfectly for hours at a time under the conditions of torpedo control, yet they cannot be depended upon absolutely, and absolute dependence, absolute reliability in the detector are pre-requisites for a really successful dirigible torpedo.

Since the first electric oscillator of Hertz, which consisted of a bent wire with the ends very near together, a number of different types of detector have been brought out. These new types and modifications have been steadily improved in sensitiveness and reliability.

Detectors may be classified under the following titles:

Coherers.	Crystal rectifiers.
Magnetic detectors.	Electrolytic detectors.
Thermal detectors.	Electrometer detectors.
Thermoelectric detectors.	Vacuum detectors.

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A further classification may also be made which places detectors under one of two general heads, namely, potential operated detectors and current operated detectors.

The following table gives this classification according to the present theories of operation for these detectors:

Potential Operated	*Current Operated*
1. Loose contact coherers.	Magnetic.
(Filings, Lodge-Muirhead, microphonic contacts, etc.)	Thermal.
	Thermoelectric.
2. Capillary electrometer.	Crystal rectifiers.
3. Potentio vacuum detector.	Electrolytic detectors.
	Vacuum detectors.

The potential group operate like a trigger in that they control local sources of energy which effect indicator operation, and depend on the potential of the received currents.

The current operated group depend upon the current effects of the received energy. In some there is a local source of energy which is called somewhat into play by the action of the received current. The bolometer, which comes under the thermal class, is one of these. In others the oscillatory energy alone affects the indicator operation. Among these is the crystal rectifier, which, chopping off the even or odd alternations in a received wave train, leaves only impulses of one sign, positive or negative. In others still, both the incoming energy and local energy called into play by it act upon the indicator. The crystal rectifiers with a local battery are examples of these.

For torpedo control a detector must be able to withstand the heavy electrical shocks at the shortest ranges, and at the same time be sufficiently sensitive to operate the relay at distances up to eight or ten miles. In addition to this it must not be affected by the mechanical vibration and shocks met with aboard a small self-propelled craft in a rough sea,

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and remain in operative adjustment for at least one hour under such conditions.

Coherers, as before stated, are sufficiently sensitive, but their action is erratic; heavy received currents cause detrimental effects; as a whole, they are far from the solution of the detector problem.

Magnetic detectors are very stable, both electrically and mechanically; they will not burn out with the strongest signals, nor lose their adjustment when subject to severe mechanical shocks, such for instance as those arising from heavy gun fire. Their failing, however, is insensitiveness, in which they are below most detectors in use.

Thermal detectors, such as Fessenden's barreter and the bolometer, are mechanically stable, but they are subject to burnouts from strong signals, and are insensitive. The fine platinum wire, the resistance changes in which arise from temperature variations produced by the oscillatory currents flowing through it, can be fused by received currents of excessive intensity. Immunity from these burnouts can only be secured by increasing the thickness of the fine wire, but this again reduces the sensitiveness, which at the best is not even equal to that of the magnetic detector.

Thermoelectric detectors employing a junction of two dissimilar metals, such as bismuth and antimony, which, when heated by the passage through it of oscillatory currents, produce direct thermoelectromotive forces, have, like the magnetic detector, the necessary stability, but they, too, are insensitive. They are also somewhat handicapped in having a comparatively large heat capacity, so that a signal several seconds long must be sent before the temperature of the junction rises to the maximum value for a given signal intensity; likewise it requires a similar length of time for cooling. Duddell's thermogalvanometer, which is probably the most sensitive of the combined thermoelectric detector and

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galvanometer, and of thermoelectric detectors in general, though valuable for the purposes of measurements, is not sufficiently rapid or sensitive for use in a radiodynamic system.

Crystal rectifiers, sometime called also solid rectifiers, though used in about 90 per cent of radio stations, and though more sensitive than any of those hitherto described, are still too low in sensitiveness for use in torpedo control work. This has been previously pointed out in connection with the received current curve. These also can be burned out by excessively strong signals, so that readjustment is necessary, and they can be thrown out of adjustment by vibration or gun fire.

Electrolytic detectors are about equal in sensitiveness to the crystal rectifiers, but are not so much used as they were before the advent of the crystal rectifiers. They, too, are subject to burnouts, and the most sensitive types, the free point electrolytics, are not mechanically stable. The glass point electrolytic, in which the fine wire anode is sealed in glass and immersed in the acid electrolyte, though not possessing this latter defect to so great a degree is less sensitive and is also subject to burnouts.

The capillary electrometer detector (see Fig. 98), as invented by Armstrong and Orling of England, consists of a minute capillary glass tube filled with mercury. The small end of this tube is immersed in an acid solution. Under the action of a current the electrolytic polarization of the contact causes a change of the surface tension of the mercury. Under this influence the mercury rises or falls in the capillary tube. A low-power microscope is used to observe the minute motion of the mercury column. It is said a delicate capillary electrometer will give a readable deflection with an applied e.m.f. of one ten-thousandth of a volt. In order, however, to pro-

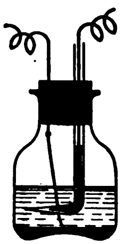

FIG. 98.

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duce a motion sufficiently to act as a relay (one-sixteenth inch), the e.m.f. must be increased to such an extent that the sensitiveness is too much reduced to make the instrument of value for mechanism control.

Vacuum detectors* have previously been discussed in detail. Some are potential operated, others are current operated, according to the circuit arrangements employed. It has been shown that with a suitable form of circuit, the vacuum detector approaches nearer the ideal by far than any other

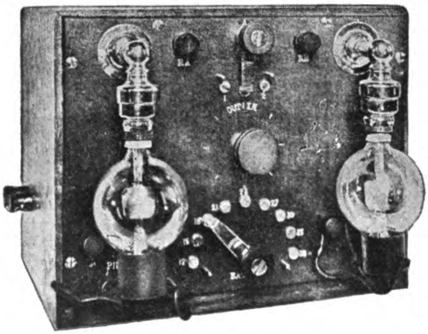

FIG. 99.

detector. Its sensitiveness is as much as 20 times as great as the best of other detectors, and it is not subject to burn-outs or severe mechanical shocks. It is this detector and the circuit which makes it potential operated that has made possible the extraordinary success attained by Mr. Hammond in the Gloucester torpedo control experiments. It is pictured in Fig. 99 as used in the DeForest System.

The hetrodyne receiver of Fessenden, depending on the principle of beats for its operation, cannot be used for relay operation, but the beats principle can be applied for amplification purposes. This will be described in another chapter.

* For detailed accounts of the very important work recently carried out by Dr. Irving Langmuir, Dr. Lee DeForest, and others, see General Electric Review, March 1915, May 1915, and Proceedings Inst. Radio Engrs., Sept. 1915.

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The frequency transformer, or tone wheel, of Dr. Goldschmidt is another application of the beats principle. Although a very efficient form of detector and very satisfactory for telephones, it is unsuitable for the operation of our most sensitive relays, which require direct current, because it, like the hetrodyne, produces an alternating current for indicator operation.*

* For complete description of the hetrodyne receiver and U. S. Navy test data, see Proc. Institute Radio Engineers, Vol. 1, part 3, 1913; a complete description of the Goldschmidt frequency transformer is contained in Proc. Inst. Radio Engrs., Vol. 2, No. 1, 1914.

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CHAPTER XXI

METHODS OF INCREASING RECEIVED EFFECTS

Various means for increasing the intensity of received signals have been proposed and utilized within the past ten years. These are called amplifiers, amplifones, variable relays, intensifiers, etc., but the generally accepted term is amplifier. It may be defined as a relay which modifies the effect of a local source of energy in accordance with variations in received signals and, in general, produces a larger indication than could be had from the incoming energy alone.

If a really satisfactory amplifier were available the seriousness of the detector problem in radiodynamics would be greatly reduced, for then a receiving detector possessing the necessary stability, though lacking in sensitiveness, could be employed.

To fulfill this requirement, an amplifier must, first of all, be capable of amplifying with a high ratio; and, next in importance to this, it must neither be subject to burnouts nor mechanical disturbances; this presupposes no necessity for readjustment for at least several hours; simplicity is also a very desirable element.

Amplifiers may arbitrarily be classified as follows:

1. Microphonic contact amplifiers.
2. Generator amplifiers.
3. Vacuum tube amplifiers.
4. Hetrodyne amplifiers.

Of these the microphonic contact amplifiers were the first to be developed, and they are most used. They consist

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essentially of a combined telephone receiver and transmitter, the same diaphragm serving both. The rectified received currents flow through the telephone electromagnet on one side of the diaphragm the consequent vibratory motion of which alters the resistance of the adjustable microphonic contact on the opposite side. Those in use for radiotelegraphy usually are so made that they will give a maximum response

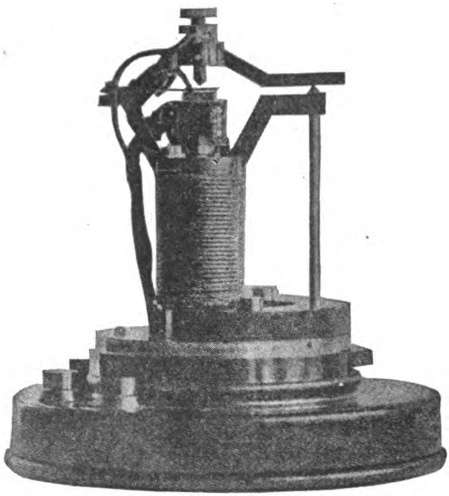

FIG. 100.

only for impulses of the correct group frequency. These are called spark-tuned or monotelephone relays. The common types employ a diaphragm as the mechanically tuned element. The Pickard, Ruhmer, Brown, and Telefunken amplifiers are examples of this type. Others have a steel reed with a very pronounced period of vibration, to increase the selectivity. Lowenstein has constructed a very sensitive instrument of this type. The instrument devised by F. C. Brown is shown in Figs. 100 and 101.

This type of amplifier has the disadvantage of being subject to vibration, jars, and sounds; it also requires frequent ad-

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justment. Although exploited commercially by several leading radio companies it has never been extensively adopted for commercial use, even for radiotelegraphy.

The generator amplifier consists of a small generator through the field coils of which the rectified received currents are made to flow. The armature currents, with all the characteristics of the field currents, but much amplified, are used for indicator operation. Alexanderson has built such an

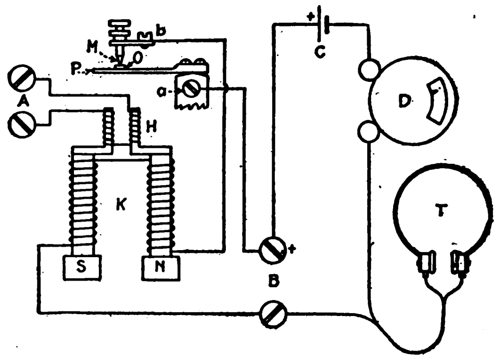

FIG. 101.
Connection diagram of Brown relay.

amplifier, which he designed especially for telephony, and succeeded in securing amplification ratios as high as 20 to 1.

It is believed that amplifiers based on this generator principle present the most satisfactory solution of amplification problems. They are not subject to mechanical disturbances; they cannot be burned out, and they can be constructed for high amplification ratios. Driven continuously by a small electric motor, a generator amplifier would require no attention or adjustment. They also lend themselves easily to spark tuning when a variable condenser is connected across the field coils.

Vacuum tube amplifiers have been brought out independently by Lowenstein and DeForest. With three vacuum tube

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detectors arranged in cascade it is claimed amplification ratios as high as 120 to 1 have been obtained. Such an arrangement is shown in Fig. 102.

These instruments though possessing a high amplification ratio, and not greatly affected by jars or vibration, have a multiplicity of adjustments and sometimes are thrown out of operation by very strong signals, which produce the familiar "blue arc." Although not so desirable as the generator amplifier, they are much more satisfactory than the microphone amplifiers, and may yet be brought to the desired state of perfection.*

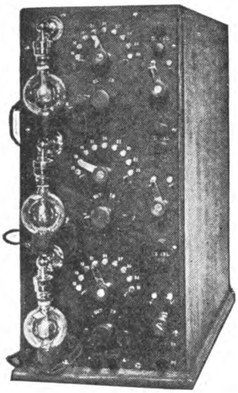

FIG. 102.

The beats principle has been applied by Fessenden for amplification purposes in radiotelegraphy.

In the latest form of this receiver, which, as before stated in the chapter on detectors, is called the Hetrodyne receiver, a local source of undamped and variable high-frequency oscillations is arranged so as to act on the receiving antenna circuit, and so adjusted that the frequency of its alternations is very nearly equal to the frequency of the incoming waves. The effect of these two very nearly equal frequencies, as in acoustics, is to form electrical beats, or alternate additions and subtractions of the two independent forces, of a periodicity equal to the difference between the two original frequencies.

The incoming frequency is fixed, but the local frequency can be altered at will, and any beat frequency desired can be produced to suit the acoustic conditions.

When no beats are produced the two frequencies are equal;

* For complete description of the DeForest Audion Amplifier, see Proc. Inst. Radio Engrs., Vol. 2, No. 1, 1914, page 24.

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obviously by calibrating the local source of oscillations, a very useful means of measuring the exact wave length of a distant transmitter is furnished.

It is said amplification ratios as high as 20 to 1 have been secured with such an arrangement. The principal difficulty with this system, however, is a reliable generator for the local oscillatory currents at the receiver. Arcs are troublesome and require constant attention; high-frequency alternators are very cumbersome (existing types weighing at least 1000 pounds, and possessing a rotor which makes 20,000 r.p.m.) and at the same time expensive. For this reason it would be next to impossible to utilize this amplifying principle for torpedo control, unless some simple and reliable wave generator be developed.*

* See Proc. Inst. Radio Engrs., Vol. 1, Part 3, 1913. The author in 1911 under the direction of Mr. Fritz Lowenstein experimented successfully with vacuum tube rectifiers as a means of producing sustained high-frequency oscillations for use in beat amplifying and selective systems and also as a wave-generator for radiotelephony. (For a very complete consideration of microphonic contact amplifiers, see extracts from a paper presented before the I. of E.E., London, which appeared in the Elec. Rev. and Western Elect., Vol. 56, Nos. 23 and 24, "A Telephone Relay," I and II.)

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CHAPTER XXII

RELAYS

The importance of a relay in a radiodynamic system is second only to that of the detector, and its requirements are just as exact. That is, it must have great sensitiveness, ruggedness, stability, and small inertia.

The sensitiveness necessary in the relay to bridge a given distance depends upon a number of factors, namely, the height and power in the transmitting antenna, and the efficiency of the receiving detector, or detector and amplifier. Obviously these factors must be taken into consideration for the reason that they are interdependent. For torpedo control it is of little consequence what the sensitiveness of any single one of the receiving instruments is so long as the final result, namely, the opening and closing of the relay contact, can be reliably effected from the transmitter at the required distance, and so long as the combination is immune to disturbances of whatever nature which must be encountered. The sole function of the detector, amplifier, and relay in mechanism control is to open and close an electric circuit at the will of the control operator. Any combination of the above-named instruments that will accomplish this result with absolute reliability is a satisfactory solution of the problems involving each of the three elements separately. That combination, however, which is most simple, least cumbersome, and least expensive is to be preferred.

In radiodynamic work where the distance is not limited by vision, as it is with torpedoes, each of the elements should have the maximum sensitiveness in order that the distance

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of operation may be as great as possible. The desirability of this is evident for such use as call-bell operation in radio signaling.

Relays are commonly classified as polarized and non-polarized. The motion of the movable element in the former reverses with a reverse in the direction of the current energizing it, while in the latter the motion is always unidirectional.

In the polarized relays either an armature consisting of a permanent magnet, or a coil through which the current flows, is the movable element.

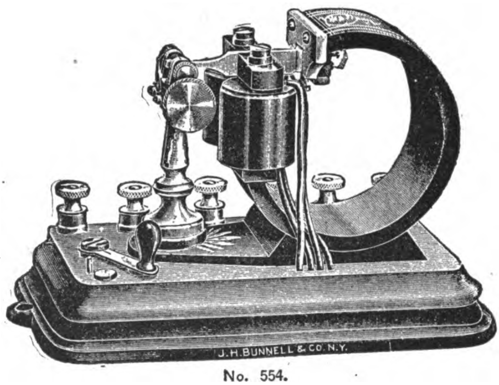

FIG. 103.
Polarized relay of the high-resistance type. (*Courtesy J. H. Brunnell & Co.*)

The non-polarized types usually have a soft iron armature or core which is always attracted in one direction regardless of the direction of the current in the electromagnet or solenoid influencing it.

The most sensitive non-polarized relays, such as those used in telegraph offices, require a current of three or four milliamperes to trip them. The most sensitive of the polarized type, as developed for use with coherer receivers by the Marconi, Slaby-Arco, Ducretet, Telefunken, and other companies, require about 400 microamperes under operating con-

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ditions. Such a relay is shown in Fig. 103. Movable coil relays, with permanent magnet fields and solid local circuit contacts as previously described are more sensitive than the above ferric armature types, requiring in the neighborhood of 200 microamperes for operation. When fitted with strong electromagnetic fields and a mercury-platinum contact arrangement, the movable coil relays can be made to operate reliably on from about 30 to 5 microamperes, depending on the mechanical disturbances encountered.

A very sensitive galvanometer of ordinary construction and about 1000 ohms resistance will give a visible deflection with less than one ten-millionth of a volt, but such an instrument requires a very solid support, such as a heavy masonry pillar, and the slightest vibration or current of air will cause the delicately suspended coil to move. Suspension coil galvanometers, though possessing very high sensitiveness, cannot be used for relays because of their extreme delicacy. Even uni-pivot galvanometers, such as the portable Paul instruments, which will give a 90-degree deflection for 10 microamperes, though at least ten times as sensitive as the author's modification of the Weston dual-pivot relay, cannot be used for relay purposes except under ideal conditions in the laboratory. They require leveling screws, and though not to quite so great a degree as the suspension coil galvanometer, are still much too delicate for use aboard a torpedo.

Likewise galvanometers of the vibration type like Einthoven's, which are capable of use in radio receiving stations for recording messages photographically over great distances, are not rugged enough for torpedo control work.

The capillary electrometer can be used as a relay, but, as before stated, its sensitiveness is not sufficiently high.

It is believed that the remodeled Weston relay, as used by Hammond, is the most satisfactory instrument for this kind of work.

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CHAPTER XXIII

TORPEDO ANTENNÆ

It is not the purpose here to discuss the many details in connection with the ordinary types of antenna used for radio work and means for supporting them. I wish merely to make a few remarks on antennæ for special use in torpedo control work, and briefly to describe the most recent proposals for improvement of this essential part of the receiving apparatus.

Obviously, as shown long ago by Marconi, the receiving antenna should be as high as possible, since the received current increases with the height. Marconi enunciated at one time an empirical law that, for simple vertical sending and receiving antennæ of equal height, the maximum working telegraphic distance varied as the square of the height of the antennæ. The experiments of the General Electric Co., of Berlin, also roughly agree with Marconi's law. Dr. L. W. Austin has worked out a formula, which, taking into account the antenna heights as well as the transmitting power and atmospheric absorption, gives the approximate signaling range of any transmitter and receiver.*

The length of the horizontal portion of an antenna is also of some importance.

We see then that for our torpedo we require an antenna of the greatest possible height and length. It is very doubtful whether, with the type of craft used for torpedoes, this height

* For a discussion of this equation, see Austin, L. W., Bulletin Bureau Standards, 1911, Vol. VII, No. 3, pp. 315–363, "Some Quantitative Experiments in Long Distance Radio Telegraphy."

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could be made to exceed the length of the vessel. The best practice, as shown in the antennæ, in use on the submarine boats of the navies of the world, substantiate this statement.

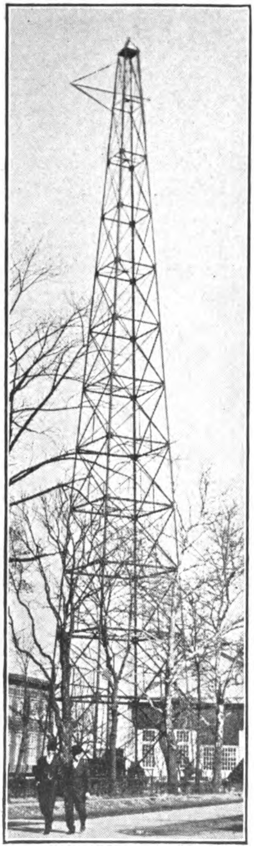

FIG. 104.
Common type of radio tower.

The 40-foot Radio in the Gloucester experiments had a three-wire inverted L-type antenna, with 6-foot spreaders of light bamboo; it was about 20 feet above the water and about thirty feet long, supported by two 3-section masts made of the lightest steel tubing consistent with strength. These weighed about 15 pounds each. The antenna wire was of the usual phosphor-bronze variety having 7 strands of No. 22 wire. A single 1,000,000-volt strain insulator between each spreader and mast-head blocks furnished the necessary overhead insulation. For the leading-in insulation a 500,000-volt roof type leading-in insulator was used. This was protected from the flying spray by an improvised hood. These insulation precautions were taken as a result of experiments which proved their necessity with the potential-operated vacuum detectors.

Experiments were made with this antenna in the effort to increase its effective length. By increasing its length it would be possible to increase its natural wave length and thus diminish the value of the energy absorbing loading inductances necessary for tuning to the transmitted waves.

In this connection a field worthy of experimentation is one

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which covers the possibilities relative to variation of transmitting wave length between two antennæ of widely different natural periods.

It is well known that a transmitting antenna will operate most efficiently only at that wave length corresponding to the natural period of the antenna with just sufficient inductance in series for coupling to the closed circuit. If the wave length be increased energy-absorbing loading inductances are necessary; if decreased, an energy-absorbing series capacity must be used.

The receiving oscillatory system likewise has a definite wave length for which it will operate most efficiently, and for the same reasons. It is known, however, that the current in an oscillatory circuit is inversely proportional to the wave length, so that although the receiving antenna is operating inefficiently at a wave length below its natural wave length, it is possible that the receiver, as a whole, works at an increase in efficiency. Again, while the receiver works best with short wave lengths, the power that can be handled by a transmitting antenna decreases with its natural wave length, and so it is possible that the large transmitting powers made possible by high, large capacity, long wave length antennæ will entirely overbalance the detrimental effects due to inefficiency in the reception of the waves. This presents an interesting field for experimentation.*

At the suggestion of Dr. Lee DeForest, the "Radio's" antenna was fitted with an extension in the form of two long wires attached to the after spreader and reaching down to a light wooden float 30 or 40 feet astern; the swift motion of the boat kept the wires taut. Long pennant-like pieces of cloth

* See "Optimum Wave-length in Wireless Telegraphy," by A. H. Taylor, Physical Review, Vol. 1, No. 4, Apr. 1913, pp. 321–325. Also, "Determination of Wave-length in Radio Telegraphy," A. S. Blatterman, Electrical World, Vol. 64, No. 7, Aug. 15, 1914, pp. 326–329.

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through which light wires connected to the rear end of the antenna were woven, and which stood out almost horizontally from the mast head when the boat was in motion, were also tried. Neither method, however, was found of any material benefit.

Water Antennæ. A very novel form of antenna was invented several years ago by Fessenden. It consists of a stream of water thrown vertically upward through a coil of copper tubing by a centrifugal force pump. Although possibly inoperative in fresh water a torpedo so equipped might be practicable in salt water, which has a higher conductivity. The hollow coil serves as a means of coupling the water antenna to the receiving apparatus.

The apparent advantage of such an aerial conductor is that it cannot be shot away by the enemy. No data relating to actual use, either experimental or practical, of an antenna of this type can be found.

The U. S. Navy has experimented with submerged receiving antennæ, for use in signaling to submarine boats equipped with radio apparatus. The antenna consisted of a type of conductor, very heavily insulated with rubber and other insulating compounds, known as "rat-tail." The antenna wire was thus completely insulated from the water, although beneath its surface. The author assisted in these tests which were made at Washington, in 1909. Audible signals were received with such an antenna in the Potomac river at Alexandria, Va., about seven miles from the two-kilowatt transmitter at the Washington Navy Yard.

These tests after considerable experimenting at Charleston and Boston with submarine boats were finally discontinued.

Another type of antenna, which has a marked directive effect, and experimented with by Dr. Franz Kiebitz, of the General Telegraph Department, of Berlin, has aroused considerable interest within the past two years. A straight wire

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is stretched horizontally a few feet above the earth, and the receiving apparatus connected in the middle. The best directions of reception are those to which the free ends of the wire point. In other forms the two ends are grounded; in still others only one end is grounded, the receiving apparatus being connected near that end.*

* See Proc. Inst. Radio Engrs., Dec. 1915: "The Effectiveness of the Ground Antenna in Long Distance Reception."

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CHAPTER XXIV

RECENT DEVELOPMENTS

Pneumatic Steering Apparatus.—The latest development in torpedo-control apparatus has been to discard electric steering gear, and to adopt apparatus designed for use with

FIG. 105.
The head telephones enable the operator to listen to the control impulses; the instrument in front of the operator is a searchlight control apparatus.

compressed air. In Figs. 105 and 106 may be seen a control operator at the Hammond Laboratory. Fig. 107 is a view of this Laboratory, and Fig. 108 is a view of Hammond's latest boat.

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This change has made possible a great simplification of apparatus, and a corresponding increase in reliability; incidentally it has also increased the accuracy of control because of the swiftness with which the operations are performed.

FIG. 106.

The gratifying results now being secured with pneumatic apparatus are ample evidence of the truth of the aforementioned statement that simplicity is a highly important factor in apparatus where adjustment is not possible; and that even very simple electric devices are uncertain in their action.

There are only three operations necessary for the control

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of a dirigible torpedo, namely: (1) rudder to port, (2) rudder to starboard, and (3) engine control. The following is one

FIG. 107.

of a number of pneumatic systems devised by the author with this "simplicity" idea in mind. In addition to the

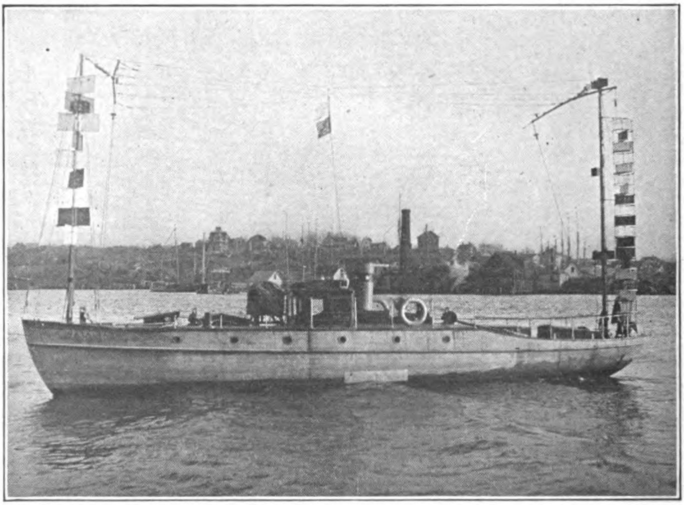

FIG. 108.

simple and rugged nature of the apparatus it also possesses the advantage that, unlike other systems, it does not require

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an especially trained operator; even with the simplest of the old systems, such as Gardner's and Hammond's, a very considerable amount of practice is necessary in order to attain expertness in the boat's control.

This system was designed in 1912 for use with selector systems in which a gradual back and forth rectilinear motion of the movable selector element, as distinguished from the

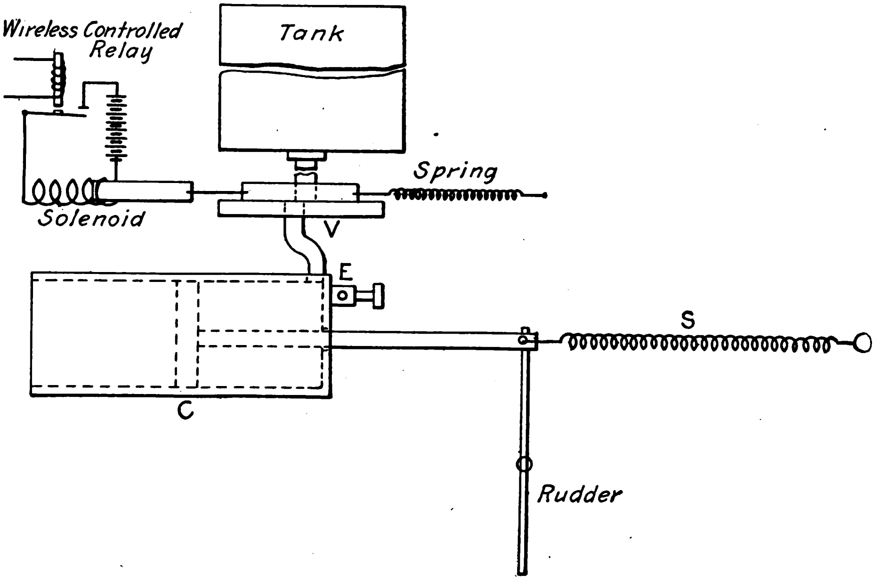

Fig. 109.

step by step circular motion of some, can be secured. Three of the author's methods as well as that of Gardner's, are adaptable for this purpose.

As shown in Fig. 109 the function of the movable selector element is to control air valves, which in turn control the energy used in performing the desired operations. A brief description will serve to explain the action of the apparatus.

Normally the transmitting impulses are of such character

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that the valve V is partially open, thus allowing compressed air to escape from the tank to the cylinder. At this normal position the pressure inside the cylinder reaches a certain value and then remains constant, due to the pull of the large spring S, and to the action of the adjustable escape valve E. If the valve V is opened wide the piston moves quickly, and with great power to the left, due to the fact that the escape valve cannot take care of this increased inrush of air; if the valve is closed farther than the normal position, the piston will be moved in the opposite direction by the spring S. By this means, the rudder, as shown, can be made to move to either side as swiftly or as slowly as desired, and maintained in any position, simply by altering the position of the steering wheel at the transmitting station. This alters the speed, or the ratio of on to off periods, of the impulses. Thus any inexperienced operator can steer the boat.

For engine control a rotary valve (not shown) operated by the solenoid, is used. This has but two kinds of positions corresponding to start and stop. When it is desired to start the engine, one turn of the steering wheel to the extreme right (farther than for the hard over position) is made; the operation for stopping is exactly the same. This can be done quickly so that no interference with the steering evolutioned need be experienced. The required air pressure is maintained in the tank by a compressor actuated by the propelling motor.

Another system of the writer's depends on the selecting action of a dash-pot retarded solenoid apparatus. By sending an impulse of one second, then allowing a short break, and then holding the impulse again, number one circuit can be operated. For the other circuits the first impulse need only be changed to 2, 3, 4, etc., seconds, according to the number of the circuit to be operated. The circuit continues

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to be closed as long as the last impulse is held; when it is stopped the selector arm returns to the normal position.

Not mentioning the work now being carried on both in the United States and in Europe on the control of trains by control systems based on electromagnetic induction at distances of a few feet, the latest development along the lines of distant control has been reported from France and Italy in connection with the "F ray" naval experiments made in the Solent. It may be worth recalling that Signor Ulivi made a number of experiments in the presence of the French authorities at Villers-sur-Mer in August of 1913.

"The 'F rays' were originally discovered by a professor at the University of Nancy, and there has been considerable controversy from time to time as to their potency, and some have even doubted their existence. On the other hand, according to certain reports, the effects obtained by Signor Ulivi were wonderful, and amazed the French authorities. No less a personage than General Joffre is said to have been impressed by them, and to such an extent that he asked the inventor to prepare a plan by means of which an enemy's magazines and powder supplies might be blown up from a distance.

"What Signor Ulivi has since done in France has remained a profound secret; in fact it is not known whether he has done anything at all. Immediately after the first articles had appeared in the papers, in August of 1913, it is understood he was asked to go to England to submit some tests to the British Admiralty. His experiments in France were chiefly carried out at Havre and Villers-sur-Mer. They were witnessed by General Joffre, General Curieres, de Castelnau, Major Ferrie, and a delegate of the Minister of War, Captain Cloitre. The first tests consisted of a series of submarine mines of which there were ten, placed at intervals of 600 meters. Signor Ulivi, at the appointed moment, touched

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a lever, and one by one the mines exploded without any visible agent. He declared that he had done it by a concentration of the power of F rays. He was next asked to blow up some powder magazines in an old hulk, which he also did successfully.

"The technical officers who had witnessed the tests next wanted to prepare mines in their own way and defied him to explode them. This he is alleged to have refused to do at one moment, and a discussion arose. Were the experiments sincere or not? The question was asked and sides were taken at the time; but the dispute was suddenly hushed up or dropped. The fact is that every subsequent move of Signor Ulivi has been shrouded in mystery."*

Self-Directing Torpedoes.

The latest tendencies along torpedo-control lines have been towards the development of apparatus which will give a torpedo the power of self-direction.

In 1912 the author, in collaboration with John Hays Hammond, Jr., developed such an apparatus, which was called an "orientation mechanism." It is more generally known now as the "electric dog." It is shown in Figs. 110, 111 and 112.

"This orientation mechanism in its present form, consists of a rectangular box about three feet long, one and a half feet wide, and one foot high. This box contains all the instruments and mechanism, and is mounted on three wheels, two of which are geared to a driving motor, and the third, on the rear end, is so mounted that its bearings can be turned by electromagnets in a horizontal plane. Two five inch condensing lenses on the forward end appear very much like large eyes.

* Extract from an article in the "London Times."

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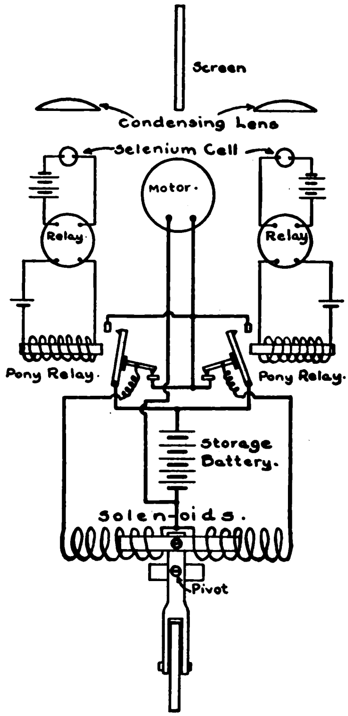
"If a portable electric light be turned on in front of the machine it will immediately begin to move toward the light, and, moreover, will follow that light all around the room in many complex manoeuvers at a speed of about three feet per



Wiring Diagram – Electric Dog.

FIG. 110.

second. The smallest circle in which it will turn is of about ten feet diameter; this is due to the limiting motion of the steering wheel.

Upon shading or switching off the light the dog can be stopped immediately but it will resume its course behind the

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moving light so long as the light reaches the condensing lenses in sufficient intensity.

"The explanation is very similar to that given by Jaques Loeb, the biologist, of reasons responsible for the flight of moths into a flame. According to Mr. Loeb's conclusion, which is based on his researches, the moth possesses two minute cells, one on each side of the body. These cells are sensitive to light, and when one alone is illuminated a sensa-

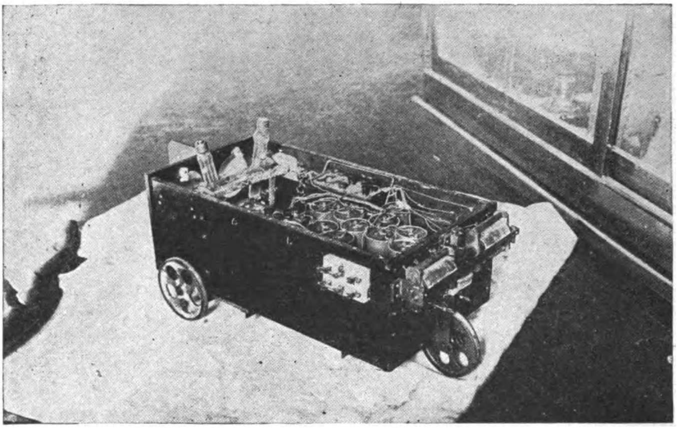

FIG. 111.
Interior of Electric Dog.

tion similar to our sensation of pain is experienced by the moth; when both are equally illuminated, no unpleasant sensation is felt. The insect therefore keeps its body in such a position, by some manner of reflex action, as will insure no pains, and in this position the forward flying motion will carry it directly toward the source of light.

"The orientation mechanism possesses two selenium cells, corresponding to the two light sensitive organs of the moth, which, when influenced by light effect the control of sensitive relays, instead of controlling nervous apparatus for pain pro-

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duction, as is done in the moth. The two relays controlled by the selenium cells in turn control electromagnetic switches which effect the following operations; when one cell or both are illuminated the current is switched onto the driving motor; when one cell alone is illuminated, an electromagnet is energized and effects the turning of the rear steering wheel. The resultant turning of the machine will be such as to bring the shaded cell into the light. As soon and as long as both

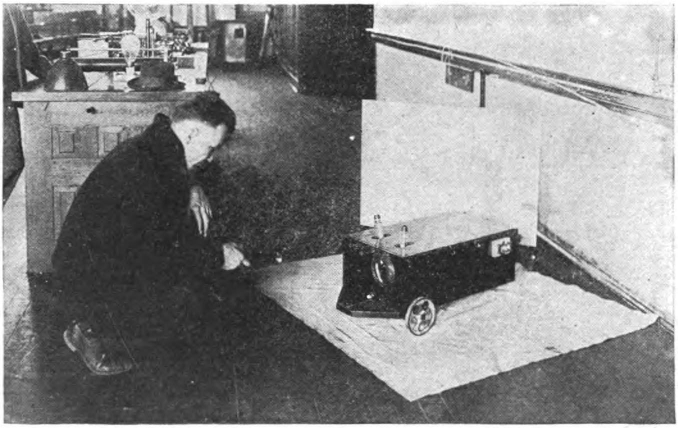

Fig. 112.
Electric Dog in Action.

cells are equally illuminated in sufficient intensity, the machine moves in a straight line toward the light source. By throwing a switch, which reverses the driving motors connections, the machine can be made to back away from the light in a most surprising manner. When the intensity of the illumination is so decreased by the increasing distance from the light source, that the resistances of the cells approach their dark resistances, the sensitive relays break their respective circuits, and the machine stops.

"The principle of this orientation mechanism has been

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applied to the Hammond dirigible torpedo for demonstrating what is known as attraction by interference. That is, if the enemy tries to interfere with the guiding station's control, the torpedo will be attracted to it. The torpedo is fitted with apparatus similar to that of the electric dog, so that if the enemy turns their search light on it, it will immediately be guided toward that enemy automatically.

"In order that the search light used by the control operator may not have this same effect, use is made of a gyroscope to keep the turn table upon which the cells are mounted, in a fixed position relative to the earth. In this way no matter how much the torpedo turns, or in what direction it is traveling the selenium cells will always face from the shore and toward the attacking battleship in the open sea.

"By means of two directive antennae, instead of two selenium cells the same principle may be applied for attraction by interference when Hertzian, instead of light waves are used. Sound waves might also be utilized in a similar manner so that the sound reaching the torpedo (which would be equipped with two submerged microphones made sensitive and directive by megaphone attachments) from the pounding of the battleships engines and other machinery, would effect its attraction in a way analogous to the attraction of a source of light for the orientation mechanism. It is just possible, too, that similar apparatus could be used for the detection of submarines, or for defense against them." *

The electric dog operates in a single plane, the horizontal; the author has developed plans for extending its operations to both horizontal and vertical planes, by using two sets of the orientation apparatus operating at right angles to one another. These plans include the use of all forms of radiant energy.

* Extract from a paper on Torpedo Control by the author in the *Purdue Engineering Review*, 1914.

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With such a double orientator a new defense against the submarine becomes possible. Captain K. O. Leon of the Swedish navy has already applied the electric dog principle to the automatic direction of torpedoes, the sound waves sent out through the water from the hull of a ship acting as the attracting stimulus; it is but a step to apply a double orientator of this type to torpedoes that will seek out and destroy any submarines within its range of hearing. This same type of automatic director is suitable for use with aerial torpedoes, explosive-laden mechanical moths, which will sweep down upon the ships of the air with a sting that will blow them into a thousand pieces. The electric dog which now is but an uncanny scientific curiosity may within the very near future become in truth a real "dog of war," without fear, without heart, without the human element so often susceptible to trickery, with but one purpose; to overtake and slay whatever comes within range of its senses at the will of its master.

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