



21st century enlightenment

GUGLIELMO MARCONI AND THE DEVELOPMENT OF RADIO-COMMUNICATION

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NOTICES

NEXT WEEK

MONDAY, NOVEMBER 29TH, at 8 p.m. Professor J. C. Drummond, D.Sc., F.I.C., Professor of Bio-chemistry in the University of London, will deliver the first of a course of three Cantor Lectures, illustrated by lantern slides, on "HISTORICAL STUDIES OF ENGLISH DIET AND NUTRITION."

WEDNESDAY, DECEMBER 1ST, at 8.15 p.m. (Ordinary Meeting). Vice-Admiral Sir Percy Douglas, K.C.B., C.M.G., will read a paper, illustrated by a cinematograph film, on "THE MANCHESTER SHIP CANAL." Sir Frederick J. West, C.B.E., J.P., Chairman of the Manchester Ship Canal Company, will preside.

PROCEEDINGS OF THE SOCIETY

SECOND ORDINARY MEETING

WEDNESDAY, 10TH NOVEMBER, 1937

SIR WILLIAM BRAGG, O.M., K.B.E., M.A., D.Sc., P.R.S., Director of the Royal Institution, in the Chair

THE CHAIRMAN, in introducing the lecturer, said : The duties of a Chairman can never be sufficiently light, and this evening I am going to make them as light as I can. I will not waste any time in introducing Sir Ambrose Fleming to you because every one of you knows what he has done in his life devoted to scientific research. We are all very lucky and proud to have him come and talk to us to-night.

The following paper was then read :—

GUGLIELMO MARCONI
AND
THE DEVELOPMENT OF RADIO-COMMUNICATION

By SIR AMBROSE FLEMING, M.A., D.Sc., F.R.S.

Albert Medallist of the Royal Society of Arts

I. TELEGRAPHY BY ELECTROMAGNETIC WAVES.

Our object to-night is to commemorate the achievements of The Marchese Guglielmo Marconi, a former Chairman of Council (1924) and Albert Medallist



By the courtesy of Marconi's Wireless Telegraph Company, Ltd.

H.E. MARCHESE GUGLIELMO MARCONI, G.C.V.O., LL.D., D.Sc.,
ALBERT MEDALLIST OF THE ROYAL SOCIETY OF ARTS AND CHAIRMAN OF COUNCIL, 1924.
Born—BOLOGNA, APRIL 25TH, 1874. *Died*—ROME, JULY 20TH, 1937.

(1914) of the Royal Society of Arts, whose work on practical wireless telegraphy by electro-magnetic waves undoubtedly laid the foundation of a great industry, and one which in its later developments has become a means of intercommunication of extreme importance and advantage to the human race.

Although Marconi was not the first person to transmit alphabetic signals by electro-magnetic waves, as shown later on, he was the first to provide a simple, portable and easily managed apparatus well adapted for use on board ship, even by unskilled persons, by which ship and ship or ship and shore stations could inter-communicate over distances vastly greater than those which can be covered by

visible or audible signals, and which thus gave a greatly increased safety to all "that go down to the sea in ships, that do business in great waters." Many hundreds of lives have thus been saved which otherwise might have ended in a watery grave.

For this achievement alone, Marconi earned the gratitude of the entire world and will be ever remembered as one of the benefactors of mankind.

It is therefore an appropriate undertaking, now that he is no longer with us, to examine the personal qualities and circumstances which enabled him to achieve so much in the upbuilding of the science and art of radio-communication, to recite the important additions he made to it, whilst we must not forget the large share other inventive minds have had in the creation of the now stupendous industry of modern wireless and broadcasting.

It will be necessary to make a brief reference to the state of knowledge when Marconi as a young man of 22 years of age first came into public notice. We need not concern ourselves with the previous attempts to conduct a limited degree of wireless telegraphy by the mutual induction of long wire circuits or by conduction through the earth as these never had more than a very restricted use.

The starting point for all effective advance must be taken to be the publication in the *Transactions of the Royal Society* in 1865 of Clerk Maxwell's great memoir on "The dynamical theory of the Electromagnetic field" in which he foretold the possibility of producing electromagnetic waves. After Maxwell's death at Cambridge in 1879 I remember speaking about it to an eminent mathematician, Sir W. D. Niven, and he said that he regarded this paper by its vast originality and power of insight to be one of the greatest productions of the human mind, and Niven was not given to exaggerated praise.

In this paper Maxwell gave mathematical expression to Faraday's conception of lines of force and extended Faraday's law of electro-magnetic induction in conductors to dielectrics showing that a changing magnetic field then creates what Maxwell called electric displacement, and electric displacement when changing produces a magnetic field. These facts he expressed in the two celebrated Maxwell equations, and these again led to a third, called the wave equation, which denotes that any sudden change in electric or magnetic force at any point in a dielectric is propagated away as a wave with the velocity of light in that medium.

It was a matter of surprise to some of us in later years when endeavouring to understand Maxwell's theory as given in his *Treatise on Electricity and Magnetism* that he had never attempted to produce his waves experimentally. That, as we know, was only done eight years after his lamented decease, by H. R. Hertz in 1887.

G. F. Fitzgerald had suggested at the British Association Meeting in 1883 that the oscillatory discharge of a Leyden jar might generate Maxwell's waves. But it was not then perceived that the condenser circuit must have a particular form in order that such radiation may take place to any large extent.

If the plates of an electric condenser such as a Leyden jar are close together, then when this condenser is discharged with resulting electric oscillations through a low resistance circuit, the stored up energy is nearly all dissipated as heat in that resistance. Hertz formed a condenser circuit with the metal plates placed as far apart as possible, namely at the ends of a straight metal rod with spark gap in the centre (see Fig. 1). This disposition then, so to speak, opens a door by which the stored up energy can escape in the form of Maxwell waves. He thus made an effective radiator or generator of these waves. Hertz proved the existence of such electro-magnetic waves by placing his oscillator at a certain distance from a sheet of

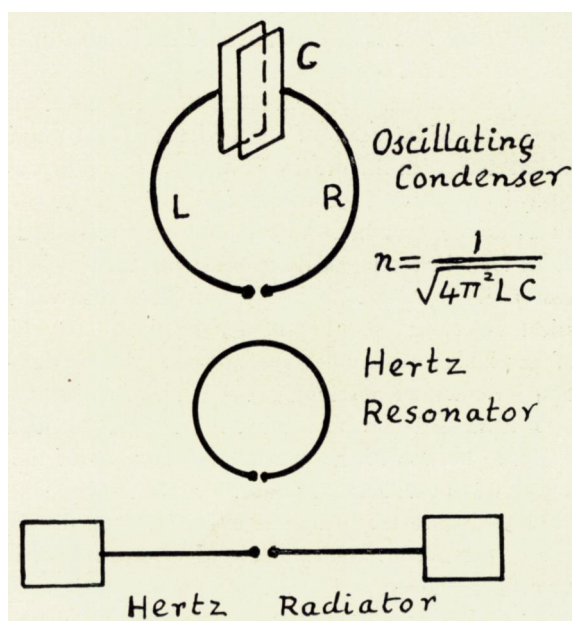


FIG. 1.

metal which reflected them and so formed a set of standing waves. He proved the existence of these by using a circle or rectangle of wire with a minute spark gap in it, and these sparks appeared when this receiving circuit was held in certain positions and distances from the oscillator. Hertz then showed that these waves could be formed into a beam by parabolic mirrors and refracted by large prisms of pitch or wax. These experiments created enormous interest and were repeated in all parts of the world. Sir Oliver Lodge, who had long previously studied the discharge of a Leyden jar, and propagation of electric waves along wires, had come very near to the production of Maxwell waves in space and the anticipation of Hertz's results.

The chief efforts of physicists were, however, at that time directed to producing shorter and shorter electric waves and obtaining quasi-optical results with them.

Righi, Bose, Lebedew and others worked in this direction, and finally, in 1923, E. F. Nichols and J. D. Tear working at Cleveland, U.S.A., succeeded in generating by electric discharge waves of $1/100$ inch wave length which were shorter than the longest known dark heat waves of $1/75$ th inch in length. They thus closed up the gap and proved identity between the radiation generated thermally and by electric discharge.

2. SUGGESTIONS FOR USE OF LONG MAXWELL WAVES

Meanwhile in 1892, Sir William Crookes had written for the *Fortnightly Review* a remarkable article in which he predicted the employment of long electromagnetic waves for telegraphy without giving any details of the proposed apparatus. He had seen certain experiments made by D. E. Hughes in 1879 which seem to have given birth to this idea. Hughes, the inventor of the microphone, had then discovered that a loose contact between a metal and carbon rod or a tube loosely full of metal particles was sensitive to electric sparks at a distance. Hughes had joined in series a Bell magneto telephone, a metal microphone and one or two voltaic cells, and found that sounds were heard in the telephone when a spark induction coil was set working at some little distance. Hughes had thus anticipated a fact rediscovered later in 1884 by Calzecchi-Onesti in Italy, by E. Branly in 1891 in Paris, and Lodge in Liverpool, that such loose contact had a large electric resistance until a small electromotive force was applied to it. Then the resistance suddenly fell. It seemed as if the small E.M.F. caused the contacts to stick together. Lodge, who independently also discovered this fact, called such a loose contact a *coherer*.

Branly had also found that a loose collection of metal filings was sensitive to an electric spark at a distance but it was not until later than it was recognized that this effect was due to the electromagnetic waves sent out from the spark.*

3. THE BEGINNINGS OF ELECTRIC WAVE TELEGRAPHY. WORK OF SIR OLIVER LODGE

In June, 1894, Sir Oliver Lodge gave a brilliant lecture at the Royal Institution, London, on "The Work of Hertz," whose death had taken place six months before. In this lecture he employed his coherer as a detector of electric waves

* Several observers prior to Hertz had noticed effects which were in all probability due to electromagnetic waves. In the *Journal of the Franklin Institute*, U.S.A., for September 1937, Mr. Nathan G. Goodman drew attention to the experiments of Edison in 1875 on the supposed Etheric Force which could produce small sparks between the closely adjacent finely pointed blacklead pencil tips held in line with each other. Experiments were made in 1876 by Professors Elihu Thomson and Houston with an induction spark coil which had one of its spark balls connected to earth and the other by a wire to a tin cylinder held about 6 feet above the coil. When the coil was in action small sparks were obtained from metal objects all over the building and also with the above Edison detector. But long before this Joseph Henry in America in 1842 had noticed the oscillatory character of Leyden jar discharges, and that effects were produced at a distance by it in forming small sparks which did not appear to be merely due to Faradayic electromagnetic induction.

and experimentally showed some of Hertz's important discoveries. This lecture undoubtedly stimulated the minds of some persons to consider the practical application of electric waves to telegraphy or the conveyance of intelligence to a distance. There was not, however, any direct reference to this use in the above mentioned lecture. To do this it is necessary to be able to transmit two different signals, such as the *dot* and *dash* of a Morse code or the right and left deflection of a magnetic needle or pen, or a small and large deflection of a spot of light as in the Kelvin Mirror Galvanometer.

In September, 1894, the British Association met at Oxford, and Sir Oliver Lodge was requested to repeat his lecture on the work of Hertz. But meanwhile a suggestion from Dr. Muirhead, an eminent telegraphist, had born fruit in his mind and he provided on his lecture table a Kelvin dead beat signalling mirror galvanometer and also a Morse inker, in order to show to his audience the transmission of alphabetic signals by electric waves. With this object he placed a Hertz oscillator and induction coil with a key in the primary circuit in the Clarendon laboratory, and connected the spark balls of the oscillator to the secondary circuit of the coil. In this way, by pressing the key for long or short periods of time, longer or shorter trains of waves could be emitted by the oscillator. Then on his lecture table in the Museum lecture room, at a distance of about 180 feet with two intervening stone walls, he had as his receiving apparatus his coherer in series with a single voltaic cell and a mirror galvanometer of dead beat type. Also he had arranged a tapper like that of an electric bell to tap the coherer back to a non-conducting state after the reception of a signal. He showed that when the induction coil key was pressed for a short time a small deflection of the mirror galvanometer took place, but when for a longer time a larger deflection occurred. Hence he was able to transmit a dot or a dash signal and by suitable combinations to send any letter of the alphabet on the Morse code and consequently intelligible messages.

He had also on his table a Morse inker (so he tells me), and could have used it with a sensitive relay to print down the signals, but as he wished the audience to see the actual signals he preferred to use the mirror galvanometer. It is, therefore, unquestionable that on the occasion of his Oxford lecture in September, 1894, Lodge exhibited electric-wave telegraphy over a short distance.

What then was needed to render it practically useful over long distances which could be reckoned in miles rather than in feet? Two things were yet required. First, some form of oscillator which could emit electric waves far more powerful than those employed by Lodge on this occasion, and, secondly, certain constructional improvements in coherer and tappers which could render it quicker in action, more certain in operation, and capable of being handled and used by persons of no great scientific skill. At the time of Lodge's lecture a young investigator of only 20 years of age was engaged in experiments in his father's garden at Pontecchio near Bologna, Italy, in search of means to supply the above-mentioned requirements.

4. WORK OF GUGLIELMO MARCONI

This young experimentalist, Guglielmo Marconi, possessed even at 20 years of age very remarkable inventive abilities and scientific insight. He saw the defects in the apparatus of much older workers, and realised quickly what was required to make a practically useful system of electric-wave telegraphy.

At the transmitting end he had two pair of spark balls of a type previously used by Professor Righi in his work: one of these Marconi connected to a long vertical wire upheld by post and at the top of this wire was a metal plate or cylinder. The other terminal spark ball he connected to a metal plate sunk in the earth. He thus made a Hertz oscillator, but one of much greater radiating

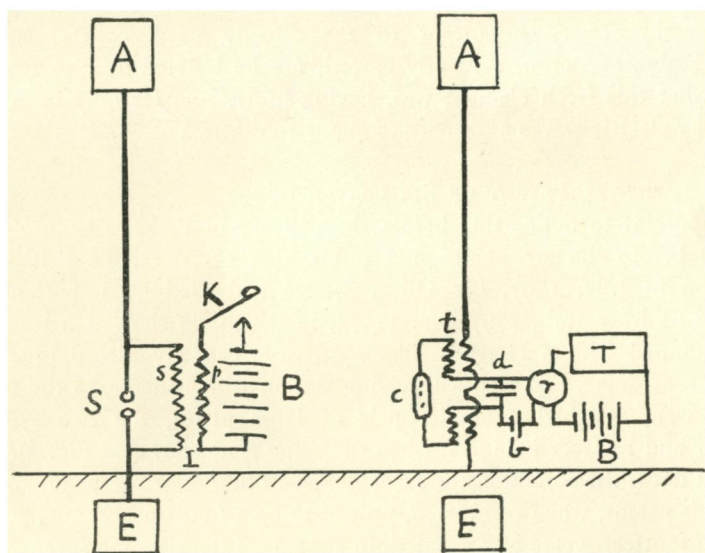


FIG. 2.—FIRST MARCONI SYSTEM, 1896.

power than any previously used. It had this greater power because it had much larger electric capacity, and could store up more energy to be released in the form of a Maxwell wave at each spark discharge. Marconi made practical improvements in the construction of the coherer and tapper, and employed a sensitive telegraphic relay and single cell in series with the coherer to operate a Morse printer. All the elements he employed in his receiving arrangement were the same in essential nature as those previously used by Lodge and also by a Russian physicist, Popoff. But he connected one end of his coherer to earth and the other end to a long vertical wire similar to that attached to one of the spark balls (*see* Fig. 2). He enclosed the whole receiving apparatus in a metal case to preserve it from being affected by the adjacent transmitter spark.

Marconi must have completed this apparatus in Italy about the end of 1895 or early part of 1896, because he then came to England and applied for British

patent protection for it on June 2nd, 1896, No. 12039. He brought an introduction to Sir William Preece, then Engineer-in-chief of the British Post Office, who afforded him facilities for demonstrating its powers under the ægis of the British Postal Telegraph Department. During the rest of 1896 and the first half of the year 1897 Marconi made demonstrations with his apparatus to officials of the General Post Office and others.

In June, 1897, Preece gave a lecture at the Royal Institution on "Signalling through Space without Wires," and he introduced Mr. Marconi to the audience and mentioned the results obtained with his apparatus. Preece said "excellent signals" have been transmitted across the Bristol Channel nearly nine miles and on Salisbury Plain over four miles. It was, therefore, clear that Marconi had added something very important to the already used coherer apparatus. Professor Slaby, of Berlin, evidently agreed, for he hurried over to England to discover what this fresh element was, having himself so far only been able to telegraph by electric waves a distance of about 100 metres or so.

5. A FUNDAMENTAL PATENT OF SIR OLIVER LODGE

It is important to notice that before the delivery of Preece's lecture in June, 1897, and before the acceptance and publication of Marconi's British patent specification in July, 1897, Sir Oliver Lodge had filed an important patent application on May 10th, 1897, No. 11575, in which he showed a transmitting station equipped with a Hertz oscillator of large capacity placed in a vertical position out of doors, and also a receiving station with coherer, to the terminals of which were attached a similar pair of large plates, the two systems of transmitter and receiver being tuned to the same frequency (*see* Fig. 3). Lodge clearly laid down the conditions under which such tuning or resonance could take place. This patent, when completed, proved to be a fundamental one, and at the end of the fourteen years was granted, in 1911, an extension for seven years and acquired by the Marconi Company. The constructions described therein had been put into practical operation by the Lodge-Muirhead Syndicate.

A very exhaustive analysis of this important British patent specification was made and published as a pamphlet in 1911 by the late Professor Silvanus P. Thompson under the title "Notes on Sir Oliver Lodge's Patent for Wireless Telegraphy."

6. WORK OF ADMIRAL SIR HENRY JACKSON

It is also necessary to notice the pioneer work of Admiral Sir Henry Jackson with respect to wireless telegraphy for the Navy. In 1891 the idea first came to him of utilising Hertzian waves for naval signalling. Between the end of 1895 and July, 1896, he devised a practical form of coherer. By the end of 1896, without knowledge of Marconi's work, Jackson had been able to effect communication between places several hundred yards apart. In 1896 he learnt of Marconi's inventions. But Jackson seems independently to have discovered

the increased signalling distance obtained by " earthing " one ball of the oscillator and attaching a long vertical wire to the other ball. In view of the above-mentioned facts of history, it is impossible to designate Marconi (as is sometimes done) the sole inventor of wireless telegraphy by electric waves. He made important constructional improvements in the coherer, tapper and receiving apparatus generally, by which it was made more certain in operation and capable of being handled by non-scientific persons. His great contribution to it was the elevated aerial wires with capacity at the top and the earth connection, both to the oscillator and coherer, by which an immense extension of range was at once

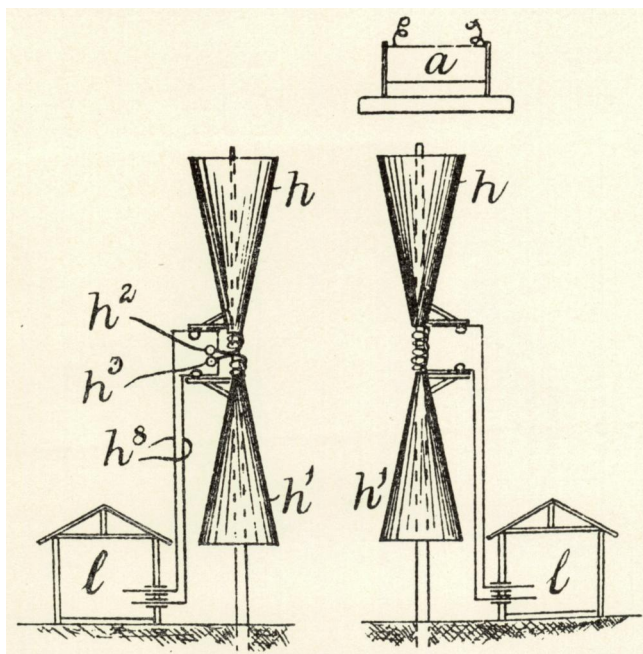


FIG. 3.—LODGE AERIALS FOR SYNTONIC WIRELESS TELEGRAPHY, FROM FIG. 5 IN LODGE'S BRITISH PATENT SPECIFICATION NO. 11575 OF MAY 10TH, 1897.

bestowed, and by this he converted an experimental apparatus into a practical system of wireless telegraphy by electric waves.

7. MARCONI'S PRACTICAL ACHIEVEMENTS

When I made Mr. Marconi's acquaintance at Bournemouth at Easter, 1898, he was working this apparatus between Alum Bay, Isle of Wight and Bournemouth, a distance of fourteen miles over sea. I do not yet forget my surprise at seeing the paper tape run through the Morse inker with intelligible dot and dash signals printed upon it conveying a message to me. Lord Kelvin, who inspected the

working about the same time, sent a message to Sir George Stokes and insisted on paying for it at Post Office rates, as an evidence of his opinion of its quite practical character.

In the early part of 1899 Marconi shifted his station to the South Foreland Lighthouse, near Dover, and set up another at Wimereux, near Boulogne, in France, and sent messages across the English Channel. This attracted great attention from the Press and public interest. Marconi had by that time seen that the coherer in his original form of receiver was not placed to advantage at the base of the receiving aerial where the potential amplitude was small. Hence, he introduced a small transformer called a "jigger," which changed the large current

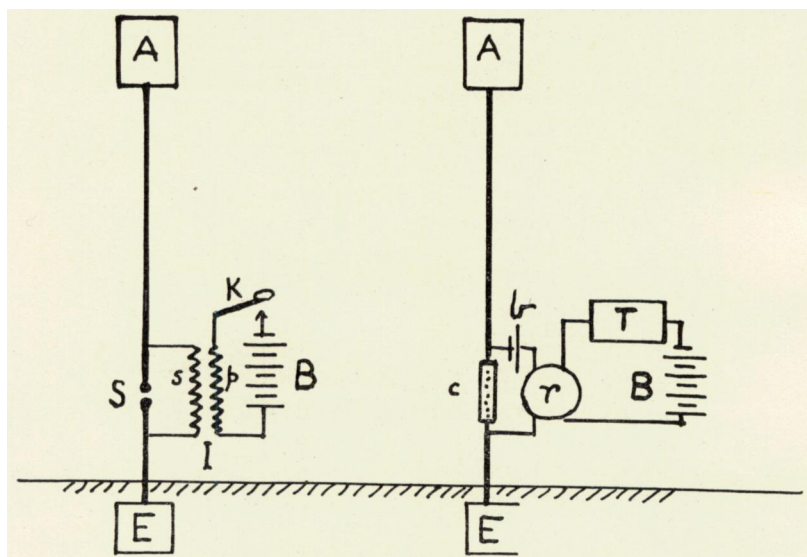


FIG. 4.—SECOND MARCONI SYSTEM, 1898.

variations at the base of the aerial wire into large potential variations operating on the coherer (*see* Fig. 4). With this arrangement he worked until the beginning of 1900 and then made an additional improvement.

8. SYNTONIC WIRELESS TELEGRAPHY

Marconi had at that time clearly understood that the form of aerial he had been using radiated its energy at each spark discharge in the form of a single or, at most, one or two vibrations, and thus could not, as Lodge had previously explained, fulfil the requirements for resonance or tuning. For this purpose it was necessary to provide a capacity which could store up a large amount of energy to be drawn off by the aerial and radiated in trains of many waves (*see* Figs. 5 and 6).

Marconi accordingly provided himself with a number of Leyden jars and

joined several of these in parallel and the whole lot in series with a pair of spark balls and with a single turn of thick wire wound on a square wooden frame. Over this he wound many turns of insulated wire, which was inserted in between the aerial and the earth, and included a variable inductance coil for tuning. He employed the same receiving circuit as before, but tuned all four circuits, two in the receiver and two in the transmitter, to each other and to the same frequency.

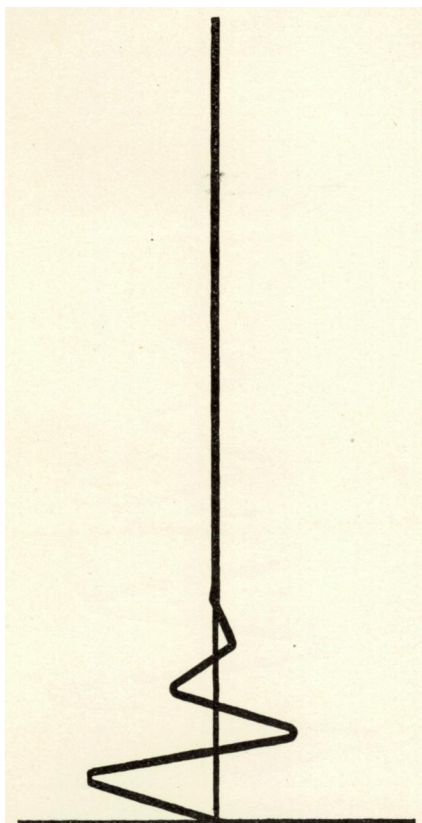


FIG. 5—STRONGLY DAMPED OSCILLATIONS.

Marconi found that this arrangement gave increased range and privacy (*see* Figs. 7 and 8). He described this syntonistic system to the Royal Society of Arts on May 17th, 1901, and applied for a British patent for it, No. 7777 of 1901, for the combination.

The validity of this patent was subsequently upheld in the British Court of First Instance. On the other hand, the above-mentioned tuning patent of Sir Oliver Lodge of 1897 was held by Lord Moulton to be the fundamental one and it was therefore acquired by Marconi's Company in 1911, after being

extended by Lord Justice Parker for seven years. Sir Oliver Lodge must, therefore, be considered as the true initiator of syntonistic wireless, but the methods adopted by Marconi for putting it in practice were also upheld by the Courts. Marconi had an especial power of reducing general principles to practice and devising the form of apparatus which could give best effect to them.

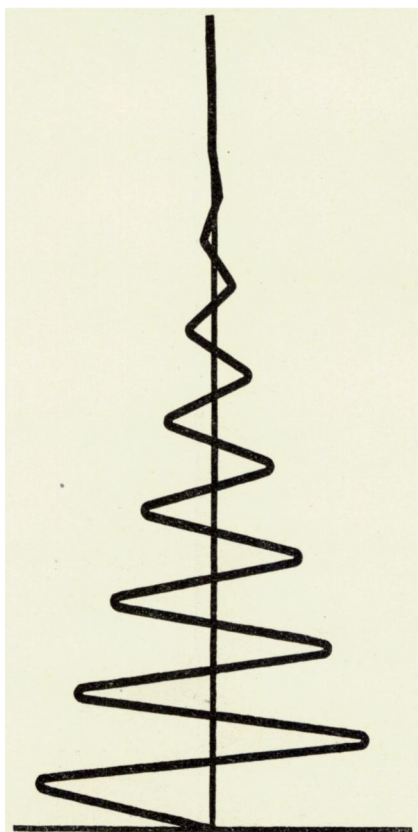


FIG. 6—FEEBLY DAMPED OSCILLATIONS.

9. TRANSATLANTIC WIRELESS TELEGRAPHY

In 1899 the British Association met at Dover, Sir Michael Foster being President. I was asked to give the evening lecture, the subject being "The Centenary of the Electric Current." By arrangement with Marconi an aerial wire was erected on the Dover Town Hall and messages were exchanged by wireless with the President of the French Association, then meeting at Boulogne. At that time Mr. Marconi had gone to the United States to demonstrate his system there, and on his return, having worked over a distance of seventy miles or so, he was fully determined to attempt the feat of transmitting message-bearing electric waves across the Atlantic Ocean.

It was clear, however, that to have any chance of success it would be necessary to replace the simple physical laboratory apparatus so far used by engineering plant of some considerable power. The directors of Marconi's Wireless Telegraph Company, formed in 1897 to operate his system, engaged me as adviser to specify the engineering plant which would be required. A rough guess suggested that 25 horse-power might be perhaps enough for a first experiment. I accordingly ordered a 25-h.p. oil engine and purchased an alternating dynamo of similar

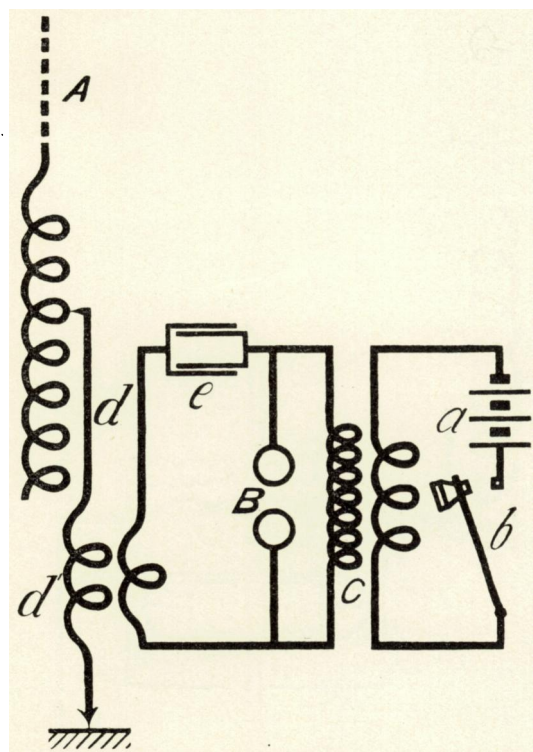


FIG. 7—THIRD OR SYNTONIC MARCONI TRANSMITTER, 1900.

power, and specified for two transformers changing from 2,000 to 20,000 volts, and designed some condensers consisting of glass plates coated with tinfoil, immersed in glazed stoneware pots filled with linseed oil.

A site for the transmitting station was selected at Poldhu, a lonely place on the coast of Cornwall, and a plan for a first station building furnished also by me. In October, 1900, Mr. R. N. Vyvyan, one of the Marconi Company's engineers, was sent to Poldhu to erect this plant, and the writer went down in January, 1901, to test it. The scheme of circuits employed in the transmitter was a double transformation system described in the British patent specifications No. 22126 of 1900 and No. 3481 of 1901 (*see* Fig. 9), granted to me. The object of this double

transformation system was partly to increase the number of radiated trains of oscillations and approximate to a continuous wave but also to reduce the necessity for interrupting a large electric current in making alphabetic signals.

Meanwhile Mr. Marconi had ordered a system of masts to be erected in a circle to sustain a conical aerial of many wires. The method adopted of staying the masts was, however, defective, and they were blown down in a storm in September, 1901. But a pair of masts was put up to support a fan aerial. Much work had to

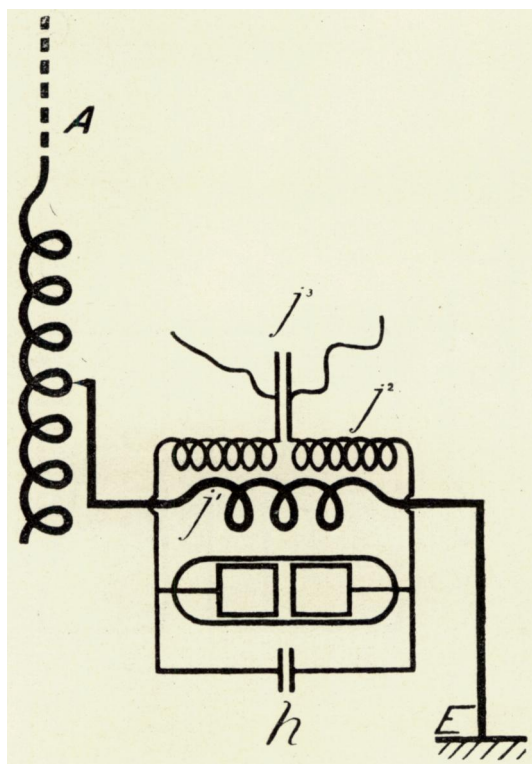


FIG. 8.

be done, both by the writer and by Mr. Marconi, before the above-mentioned plant was ready for a test. But when it was found capable of giving strong signals at Crookhaven, in the south of Ireland, Mr. Marconi considered a transatlantic test might be made, and in December, 1901, he went over to Newfoundland, taking with him two assistants, Mr. G. S. Kemp and Mr. P. W. Paget, and some kites and balloons to elevate a temporary aerial wire.

After some trials he was able to hear by telephone placed in series with a self-restoring coherer, triple sounds which were the Morse code for the letter S which he had directed should be signalled from Poldhu at 3 to 6 p.m. on certain

days. It was then clear that some small part of the electric-wave energy sent out from Poldhu had found its way across the Atlantic to St. John's, in Newfoundland and it seemed demonstrated that with more energy intelligible messages could be sent. This result, however, excited some doubt and criticism. Physicists such as the late Lord Rayleigh considered there was something unexplained about this achievement and that it could not have been due to mere bending or wave diffraction.

10. EFFECT OF ATMOSPHERIC IONISATION ON ELECTRIC WAVE TELEGRAPHY

In the discussions that took place concerning Transatlantic wireless telegraphy

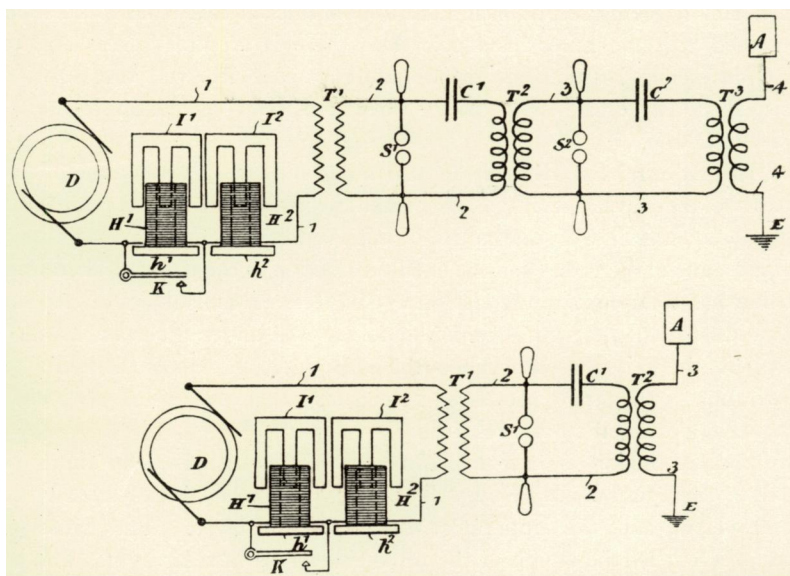


FIG. 9—SCHEME OF CIRCUITS OF DOUBLE TRANSFORMATION SYSTEM EMPLOYED AT POLDHU IN 1901 FOR THE FIRST ELECTRIC WAVE TRANSMISSION OF LETTER "S" ACROSS THE ATLANTIC OCEAN. FLEMING SPECIFICATIONS.

Mr. Oliver Heaviside and Dr. Kennelly suggested that the ionisation of the earth's upper atmosphere by solar light had the effect of making a conducting layer at a great height in the air, which afforded a reflecting or refracting region causing curvature of long electric waves round the earth. Much work had to be done before the true function of the atmosphere on long electric wave propagation was fully understood.

In 1902, in a voyage across the Atlantic on the s.s. *Philadelphia*, Marconi first noticed that there was hardly any difference in the strength of the received signals sent out from Poldhu by day and by night up to 500 miles or so. But beyond 700 miles day signals failed, but night reception was good up to 1,551 miles and signals decipherable up to 2,099 miles. Mathematicians then attacked the

problem of wave diffraction round a conducting earth for electric waves of 1,000 feet and upwards wave length.

The first results obtained by Professor H. M. Macdonald were criticised by the late Lord Rayleigh and by M. Poincaré, but subsequent work by J. W. Nicholson, Poincaré, A. E. H. Love, March, Rybzyński and G. M. Watson led to the conclusion that for distances above 1,200 miles or so over the earth mere diffraction could not possibly account for the strength of signals received by electric waves of the length then used.

Moreover, in his Nobel Prize Lecture in December, 1909, Marconi mentioned some freak transmissions noticed in ship to shore wireless. Low-power ship plant, normally giving reception limited to 200 miles at that date, could sometimes be received at 1,200 miles distance. Also there is at some places and times a curious difference between north-and-south or east-and-west transmission. At times near sunrise or sunset a shorter wave is better received across the Atlantic than a longer one.

The late Admiral Sir H. Jackson also made numerous observations, recorded in a paper to the Royal Society, of abnormal effects in transmission, and the results of interposed hills and of the nature of intervening soil on wireless propagation. It is impossible to mention even the smallest fraction of the theoretical and practical work that has been done in the last thirty-six years on the subject of electric-wave propagation round the earth. Suffice it to say that above a certain height in the atmosphere there is a region called the *ionosphere*, in which there is a varying electrification of the air by presence of electrons or particles of negative electricity and positively charged atomic residues.

This ionised region is now considered as distinguishable into four districts denoted by the letters E_1 , E_2 , F_1 , F_2 . The lowest region, E_1 , is called the Heaviside-Kennelly layer and the uppermost the Appleton layer. The cause of this ionisation is chiefly the action of the ultra-violet rays in solar light. But perhaps some contribution may be made by particle bombardment from solar or cosmic emission. The ionisation increases as we go up in the air. The lower limit of it comes nearer to the earth by day as compared with that at night. Then we have to distinguish two wave regions. Part of an emitted wave travels along the earth's surface, and is called the *ground* wave, and another part, called the *sky* wave, travels up into the ionosphere and is then reflected or refracted downwards again and reaches a place on the earth far distant from that of its origin (*see* Fig. 10).

There is a difference in the effect of the ionised air on the waves, whether they are long, 1,000 metres and upwards; medium, 200 to 500 metres; short, 16 to 200 metres; and ultra-short, below 16 metres, in wave length. There is a difference in the day and night effect, and some wave-lengths are affected by the sun spot period of 11·3 years.

Moreover, there are vagrant waves called atmospherics produced by near or distant lightning flashes. The results are extremely complicated, and we cannot here give even the faintest outline of the work done on the subject or the names of

the workers. We must pass on to notice Marconi's work on directive wireless telegraphy.

11. DIRECTIVE WIRELESS TELEGRAPHY

In 1905 Marconi experimented with aerial wires only a short part of which was in a vertical direction and the rest horizontal and parallel to the surface of the

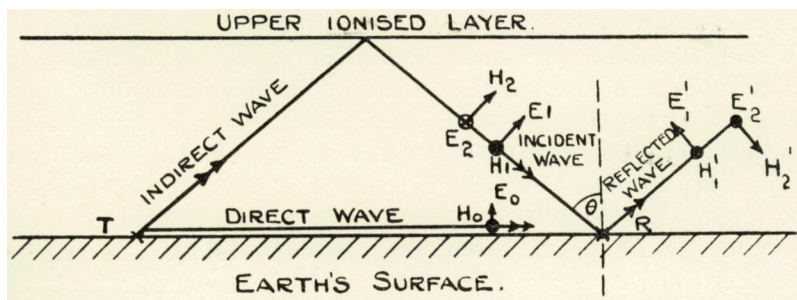


FIG. 10—A DIAGRAM TAKEN FROM A MEMOIR BY DR. R. L. SMITH-ROSE, PUBLISHED BY THE DEPARTMENT OF SCIENTIFIC AND INDUSTRIAL RESEARCH, SHOWING THE MANNER IN WHICH A DIRECT OR GROUND WAVE AND AN INDIRECT OR SKY WAVE REACH A RECEIVING STATION.

earth (see Fig. 11). He found that such a bent antenna radiates most strongly in a direction opposite to that to which the free end points. Also it receives best waves from the same direction. By means of such an aerial, only 2 metres of which was vertical and 60 metres horizontal, Marconi was able to locate very closely the

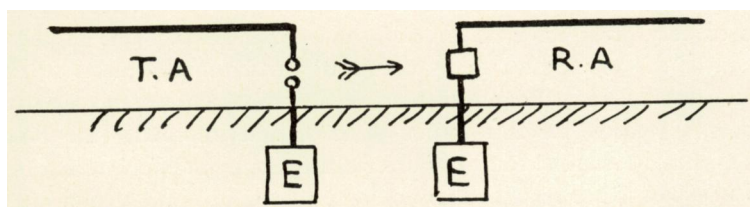


FIG. 11—MARCONI DIRECTIVE AERIALS, 1906 (*Proc. Roy. Soc.*).

direction of an invisible ship 16 miles away by shifting round the horizontal part of the aerial in various directions and noting when the received signals were strongest.

This discovery illustrates very well Marconi's remarkable power of intuitive invention. He did not arrive at any of his results by mathematical prediction. In fact I think his mathematical knowledge was not very great. In the case of this bent antenna the theory of it was only worked out by me nearly a year later in a paper sent to the Royal Society. In addition to this power of intuitive anticipation he possessed enormous perseverance and power of continuous work.

When once he had hit upon a new idea or promising line of research, he worked at it all day and every day until he had exhausted its possibilities. Added to this he enjoyed a freedom from any necessity for other income-earning work. Much of our scientific research work is done by men who can only give to it overtime from professional occupations. Moreover technical invention requires considerable expenditure.

Marconi possessed great power of persuading others to believe in the ultimate commercial success of his work as he himself did. Hence by the formation of the Wireless Telegraph and Signal Company in 1897 he had the means placed at his disposal for such large-scale experiments. The problem of directive wireless telegraphy was soon seen to have very great importance. If a ship could ascertain the direction of a shore station and if such stations were established in known positions, then the ship could find its position in fog or cloudy weather when astronomical observation were impossible. This problem engaged the attention of two other Italian investigators, Bellini and Tosi, who made use of the property of a closed circuit of receiving electric waves best in the direction of its own plane. Hence, if two coils of insulated wire are wound in many turns on a wood frame and fixed at right angles to each other, but rotatable round their common vertical axis, then we can find the direction in which an electric wave is moving by turning these coils until the signals are loudest in one coil and zero in the other.

Dr. J. Robertson improved this method by making one coil smaller than the other, and joining the two coils in series. A reversing switch was included so as to make the current in the small coil add to or oppose the current in the large coil. Hence, by noting when the reversing of the small coil connection made no difference in the loudness of the signals, it was then known that the plane of the small coil was at right angles to the direction of the arriving waves. There are, however, sources of very great error in direction-finding on ships. One of these is the deflection of the arriving waves by the metal parts, funnels, masts or rigging of the ship. Captain H. J. Round, of Marconi's Company, devoted special attention to finding a remedy for this source of error and improving the Bellini-Tosi direction-finder. Another source of error called the night effect, which may cause serious mistakes if not remedied, is due to a change in the direction of the wave front of the indirect wave coming down from the ionosphere by night which is then no longer perpendicular to the direction to the transmitting station. Mr. F. Adcock has devised means for overcoming this source of error. A very full discussion of the causes of error in wireless direction finding has been given by Dr. R. L. Smith-Rose in a pamphlet published by the Department of Scientific and Industrial Research. As regards means for projecting the electric waves in a given direction, Marconi followed Hertz in using metal parabolic mirrors. This method is only available for short waves, because the dimensions of the mirror must be large compared with the length of wave employed if it is to be effective. Marconi was able, however, by the use of short waves and parabolic mirrors to achieve in 1896 or 1897 wireless telegraphy over a distance of about two miles on Salisbury Plain.

12. ESTABLISHMENT OF LONG-WAVE HIGH-POWER RADIO STATIONS

The success, though for reasons then not understood, of the first Transatlantic transmission of electric waves indicated the necessity for greatly increased power and longer wave lengths if commercial radio-communication was to be established. Marconi had been interdicted from continued use of places for reception in Newfoundland by the Anglo-American Cable Company. He was, however, invited to establish a station in Canada, and selected a site at Glace Bay, Breton Island. Mr. R. N. Vyvyan was appointed managing engineer to make all the arrangements of plant. The masts at Poldhu were discarded and wooden lattice towers erected in place of them, and the engine and dynamo power increased to about 150 h.p., and the wave-length to about 8,000 metres, or nearly five miles. Those who desire to learn the history of the enormous amount of experimenting and expenditure which had to be made over a period of four years before anything approaching regular commercial wireless telegraphy was established across the Atlantic, should consult the excellent book "Wireless over Thirty Years," by Mr. Vyvyan, who was Marconi's chief collaborator in all this work, and therefore writes with first hand knowledge. He there gives a vivid account of Marconi's great courage, resource and fertility of invention and power of working even sixteen hours a day to meet and overcome the unexpected difficulties arising from the ever-changing electrical state of the atmosphere as regards electric wave propagation round the earth.

The arrangements for wave generation, as used first at Poldhu, were in time greatly changed by Marconi. In place of glass-plate condensers he made large air condensers with metal plates hung a foot apart. In place of the alternators and transformers he used direct current dynamos joined in series charging a high-voltage storage battery, and he devised a form of rotation spark discharger which effectually destroyed arc discharges whilst allowing the oscillatory condenser discharge to take place (*see* Fig. 12). A new station on this system was established at Clifden, on the west of Ireland, to correspond with Glace Bay, and finally, after incredible labour, a full public wireless service both ways across the Atlantic was established in February, 1908. Later on the Clifden station was put out of action in the Irish "trouble" and another station built on the side of Snowdon near Caernarvon. This station was worked with high-frequency Alexanderson alternators. But finally all methods of electric wave production by spark, arc or alternator were put out of use by the improvements in making high-power thermionic valves, and the discovery that they could generate undamped or continuous electric oscillations of great energy.

13. THE BEGINNINGS OF SHORT-WAVE WIRELESS TELEGRAPHY

Long-wave high-power radio stations for long-distance all-round working began to be planned or erected in various parts of the world as soon as permanent transatlantic working was assured. At Rugby we have under Post Office control one of the largest of these all-round longwave stations. But a great change in

system soon made its appearance. In 1904, when wireless telegraphy in England was brought under control of the Government, it was not desired entirely to prevent amateur research, and, therefore, amateurs were allowed to generate waves of less than 200 metres wave-length, because at that time such waves were considered useless for practical telegraphy. They were, in fact, given to the amateurs to play with, as one may give a toy to a child.

But clever amateurs soon discovered that although waves of 100 metres length did not travel far along the earth's surface, yet when shot up at the sky they could give good signals at places even beyond a thousand or two thousands miles away.

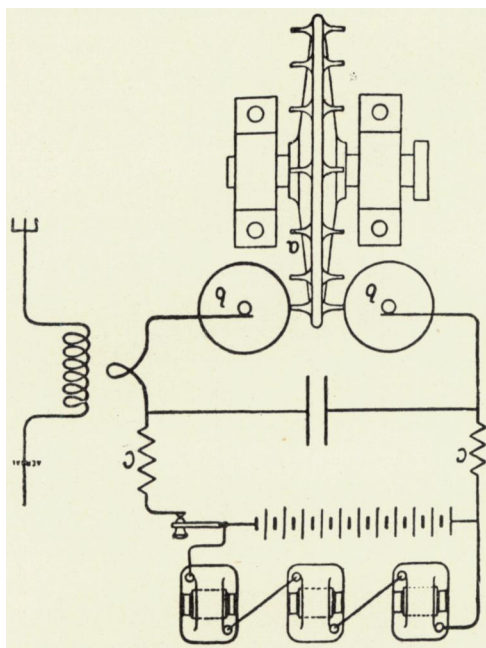


FIG. 12—SCHEME OF CIRCUITS OF MARCONI DIRECT CURRENT TRANSMITTER, AS ARRANGED AT CLIFDEN AND GLACE BAY FOR TRANSATLANTIC WIRELESS TRANSMISSION.

They were, in fact, reflected down from the upper layer of the ionosphere. Such communication could be established with power of only a fraction of a kilowatt. Experts soon recognised that a new field of research had been opened, and Marconi threw himself into it with characteristic energy. He enlisted the co-operation of Mr. C. S. Franklin, one of the Marconi's Company's engineers.

The first idea was to create a beam of short-wave radiation by means of parabolic mirrors. The use of sheet metal for mirrors of the required size was out of the question, but skeleton mirrors made of vertical wires arranged in a parabolic form act just as well. Hence such a mirror was erected at Caernarvon in 1917 and experiments tried with waves from 3 to 15 metres in wave length. Signals were

well received at Kingston, Ireland, seventy-eight miles away. Then similar apparatus was set up at Hendon, and wireless telegraphy and telephony received at Birmingham with only 700 watts power input to the transmitter at Hendon. Finally, a 12-kilowatt plant was set up at Poldhu, and the Marconi Company's yacht, *Elettra*, equipped for the reception of 97-metre waves and exploration at various distances. Very strong signals were received 1,250 miles distant by day and 2,230 miles by night, the signals being far stronger than some long-wave stations could then give.

The inventions of Mr. C. S. Franklin are of great importance in connection with this short-wave wireless.

14. SHORT-WAVE BEAM STATIONS

Mr. Franklin directed his attention to the invention of forms of aerial wire able to radiate powerful short waves. A plain aerial wire sends out as its fundamental a wave of about four times its own length. Hence, a single wire radiating 16-metre waves would emit only a feeble wave, because of its small capacity. Mr. Franklin constructed long aerial wires cut up into sections by coils or condensers, which then radiated powerful short waves. He placed a number of such aerials in a row at equal distances and in a direction at right angles to the desired line of propagation. Behind these he placed another series of wires at a distance of a quarter or three-quarters of a wave-length to act as reflectors. These aerials were supplied with high-frequency currents from powerful valve oscillators. In this way a strong beam of electric waves of wave-length from 15 to 90 metres or so could be directed at a slight angle of 10° or 15° upwards into the ionosphere, and was then refracted down to a far-distant receiving station at Australia, New Zealand or elsewhere. In 1924 tests made at Poldhu with 32-metre waves, using less than 12 kilowatt power, were well received at Buenos Aires and Australia.

15. SHORT-WAVE IMPERIAL BEAM STATIONS

The results of all these experiments made it possible for the Marconi Company to make proposals to the British Government for the erection of short-wave Beam stations to communicate at all hours of the day and night with the Dominions, and send not less than 100 words per minute for a certain number of hours per day.

The design for the valve receiving plant was entrusted to Mr. G. A. Mathieu, who had rendered valuable assistance in the short-wave tests made during the voyages of the *Elettra*. Mr. R. N. Vyvyan was appointed to carry out the construction of the Imperial Beam stations. The receiving station is always placed at some distance from the transmitting station. Thus, at Dorchester the Beam is sent to U.S.A., to Buenos Aires, Japan and Egypt, and the corresponding receiving station is at Somerton. The transmission is controlled from Electra House, London, the headquarters of the Marconi organisation. This short-wave wireless system and the Beam stations were described by Marconi to the Royal

Society of Arts in two papers on July 25th and December 26th, 1924. The effect of the great success of this beam system on the older submarine cable system was soon found to be very serious in reducing their traffic receipts. But the Government decided that it would be impolitic to allow the cable companies to be crushed out of existence, and therefore, after long discussions, a merger of interests was brought about and a Company called the Imperial and International Communications Ltd. (now Cable & Wireless Ltd.) was formed to take over the cable and wireless interests and work them jointly.

16. ULTRA SHORT-WAVE WIRELESS RESEARCH BY MARCONI

In the last few years of his life Marconi was fascinated by the problem of using electric waves of 30 cms (1 foot) or less for radio communication. He was most ably assisted by Mr. G. A. Mathieu in the design of the necessary type of valve and radiator for waves of this exceedingly high frequency, viz., nearly 1,000 million oscillations per second. Mathieu modified a mode of connection devised by Barkhausen and Kurz for such short-wave generation. So successful were some of these results that the Vatican authorities decided on Marconi's advice to adopt a 60-centimetre wave for communication between the Vatican City and Castel Gandolfo, fifteen miles from Rome.*

17. CONCLUSION

The short limits of the present address do not permit any extension of these ultra-brief references to Marconi's work nor of the names of those who have laboured in its commercial development. A fuller history of it is given in the book by Mr. R. N. Vyvyan already mentioned, and more personal biographical details in a book by Mr. Orrin Dunlop, called *Marconi, the Man and His Wireless*.

The interest to us here present is perhaps particularly in the personal qualities which marked Marconi as a pioneer in wireless communication.

In the first place he was eminently utilitarian. His predominant interest was not in purely scientific knowledge *per se*, but in its practical application for useful purposes. He had a very keen appreciation of the subjects on which it was worth while to expend labour in the above respect.

In this work he had enormous perseverance and powers of work. He was not discouraged by initial failures or adverse criticisms of his work. He had great power of influencing others to assist him in the ends he had in view. He had remarkable gifts of invention and ready insight into the causes of failure and means of remedy. He was also of equable temperament and never seemed to give way to impatience or anger, but he did not suffer fools gladly or continue to

* In this lecture questions connected with the development of wireless telephony and the thermionic valve have not been mentioned because to do so would have extended it beyond possible limits as regards time of delivery, and moreover, would have taken the subject matter outside the range of Marconi's personal work and inventions to which the address is properly and by intention limited.

employ incompetent men. He also owed a good deal to the loyal and efficient work of those who assisted him. Although born and brought up in Italy, and, I think, never in England before 20 years of age, he had the most perfect command of the English language, both in speaking and writing. The lectures and papers he gave here and elsewhere were models of lucid and accurate description. He complied in a high degree with the definition of an engineer given in the Charter of the Institution of Civil Engineers, as one who utilises and controls the energies of Nature for the assistance and benefit of mankind.

THE CHAIRMAN, in proposing a vote of thanks, said : I must avail myself of my privileges in the Chair to say how fortunate all of us are in having listened to this magnificent account of a subject of such intense interest and importance. No one could have given it better than Sir Ambrose, because he has been in it from the first, and I think he has from the first felt that romance of the story to which his beautiful address to-night owes so much. Of the many impressions I am sure this address has made upon you, the first is that of the vitality and energy of Sir Ambrose himself. He is a man of whom we are all very proud, and hope for years to come he will still maintain that energy of speech and action which are so obviously his characteristics.

Secondly, we are impressed with the wonderful story itself. I do not know of any other development which can be traced like a stream from its initial source to a broad river for the use of mankind. From the very beginning it has been a marvellous thing. I might even carry the story a stage further back because it so happens that an event of a few months ago puts the source even a little more into the past than Sir Ambrose has put it to-night. Once upon a time at the Royal Institution a certain famous discoverer was to give a lecture, and Faraday had been assisting him all the afternoon to get it ready, but at the last moment the lecturer's courage failed him and he did not turn up. So Faraday had to give the lecture from the material he had, and in the few minutes of the hour which were left after he had said all that he remembered, he spoke about thoughts of his own on the way in which electricity was propagated through space, and called it "Thoughts on Ray Vibrations" and subsequently contributed a paper of the same title to the *Philosophical Magazine*. That was in 1846. Maxwell saw that paper and based on it his electro-magnetic theory of which his mathematical development was so singularly ingenious.

Curiously enough, a few months ago we had to open at the Royal Society some old letters which had been lying in the safe for a long time, some of them marked "Sealed : not to be opened at present." One of those letters was written by Faraday, and we decided that as they had been there for a century they should be opened. I opened Faraday's letter, and it was an eerie experience to be the first man to see a signature which had been written more than a hundred years before. Faraday said, in effect (I cannot quote exactly) : "I cannot but think that the action of electricity and magnetism is propagated through space in some form of vibration." That was written in 1832. This was the source of the idea that led to the work of Maxwell, Hertz, Lodge, Righi, Marconi, and, incidentally, to the fine work of Sir Ambrose Fleming himself.

Once more let me acknowledge on behalf of you all our great debt to Sir Ambrose for the lecture that he has given us to-night. No one could have given it better or been better fitted to give it. We are very lucky to have heard it, and we shall never forget it.

MR. C. C. PATERSON, O.B.E., D.Sc., M.I.E.E. (Director, G.E.C. Research Laboratories), said : I have very great pleasure in seconding this motion which you have put. We have been listening to the life and work of one pioneer being described by another. Throughout his long and active life Sir Ambrose has himself displayed a vision and a courage of an order hardly less than that of the great man whose genius he has been explaining to us. I suppose in science a pioneer may be described as one who is never afraid of any consequences, and Sir Ambrose has always shown that intellectual courage which marks the pioneer. I think it was Dean Inge who once said : " Don't be a pioneer ; it is the early Christian who is got by the lion. The safest mountain paths are those followed by mules and asses. Tread them ! " The majority of men, whether they be mules or asses, do follow the safe paths. In the immense field of radio transmission the names of Marconi and Fleming stand together as pioneers who made safe paths for others to follow, and I see many here to-night who, like myself, are followers in the paths which were discovered by them.

We have come here to pay our tribute and acknowledge our debt to these men. Sir Ambrose Fleming's powers as a lecturer are legendary, if not miraculous. We remember them of old, and as the Chairman said, we are delighted to see he has lost none of the old power and old charm and the old lucidity. He has made this evening a memorable one as he himself would have wished.

The vote of thanks was carried unanimously and acknowledged by the lecturer.

THE RIGHT HON. LORD AMULREE, P.C., G.B.E., K.C. (Chairman of the Council), proposed a vote of thanks to Sir William Bragg for having taken the Chair, and the meeting terminated.

OBITUARY

WILLIAM PERRY, M.A.—We deeply regret to announce, what will be learned throughout the Society with equal regret, that Mr. W. Perry, the late Secretary, who only a few weeks ago was compelled by ill-health to relinquish his position with the Society, died in a London nursing home early on Saturday last, at the age of 55. He was buried at Peaslake, Surrey, on Monday. After serving the Society for ten years as Assistant Secretary, and Secretary of the Indian and Dominions and Colonies Sections, he lived for less than three years more to hold his last appointment as Secretary of the Society, a misfortune which is as much the Society's as his own. Happily those years were a period of great prosperity, and saw among other notable events the institution of the Society's new distinction of " R.D.I.," a landmark in its history.

William Perry was the third son of John Perry, of Trysull, Staffordshire. He was educated at Charterhouse (of which he was a scholar) and Magdalen College, Oxford (of which he was a Demy), and after taking first-class honours in Classical Moderations and " Greats " he became a Fereday Fellow of St. John's College. He entered the Indian Civil Service in 1909 but returned after a short period of service owing to ill-health. On his return to England he held a post in the London office of the British South African Company, but immediately on the outbreak of war joined the Inns of Court O.T.C., and went to France in 1915. He served as Captain with the R.A.S.C. until 1918, when he was sent back to England to take up a position in the Ministry of Reconstruction. Subsequent posts which he held prior to his coming to the Royal Society of Arts were with Messrs. Debenhams Ltd. (as company secretary) and on the organising staff of the British Empire Exhibition at Wembley.

Among members of the Society who were acquainted with him, whether as

“GUGLIELMO MARCONI AND THE DEVELOPMENT
OF RADIO-COMMUNICATION”

ERRATUM.—The diagrams in Figs. 2 and 4 are misplaced. They should be exchanged, the subscripts remaining as at present placed.