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Marconi, radio waves, and the ionosphere

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MARCONI: THE PERIOD 1896-1911

The life story of Marconi is too well documented to need detailed repetition, but there are certain facts about his early years which bear directly upon his quite remarkable success and indeed which relate to the early development of the subject of wireless telegraphy.

Anyone looking at the early history of radio wave propagation and of Marconi's major role in it, cannot fail to be impressed with certain facts. Thus it is surely remarkable that in February 1896 when he first took his black wireless boxes to England, Marconi was only 21 years old and it is to be remembered that not only was he a very young man but he had had very little formal training in science. The second remarkable fact is that on 2 June 1896, i.e., within a few weeks of arriving in England (he was now just 22) he filed with the British Patent Office a provisional patent specification (the first of many) to safeguard his commercial interests in wireless communication. The third striking fact is that just one year later, in the summer of 1897, at the age of 23 he and his friends formed the Wireless Telegraph and Signal Company Limited (soon to be renamed the Marconi Wireless Telegraph Company) with an initial capital of £100,000. The shares in the new company were quickly subscribed; Marconi himself received £15,000 in cash and also held a large number of the shares.

By any standards this is a remarkable record for a young man between the ages of 21 and 23, but these facts are even more remarkable when it is recalled that this young man had failed the entrance examination to the Italian Naval Academy, and later failed the entrance examination to Bologna University. Against these failures it has to be said that Marconi had attended the Technical Institute at Livorno, and for eighteen months prior to leaving for England he had been allowed, unofficially, to attend lectures given by the Professor of Physics at Bologna. In the two years or so before leaving Bologna for England, the young and wildly enthusiastic inventor had carried out valuable experiments at home on the transmission and reception of Hertzian waves. He had made some improvements in the performance of the coherer, and in particular had discovered the increased signalling range which could be achieved with an elevated aerial and with an Earth connection.

The reception which the young Marconi and his black box received at the hands of certain distinguished British scientists was not exactly cordial. Thus this is what Sir Oliver Lodge, then Professor of Physics at the University of Liverpool and one of the recognized pioneers of Hertzian wave studies, wrote in *The Electrician* in 1897:

> One of the students in Professor A. Righi's class at Bologna having heard that Professor lecture on the production and transmission of Hertz waves across space and their detection by the cohesion which they caused in a group of metallic filings, and, being gifted, doubtless with a sense of humour, proceeded to put a coherer into a sealed box and to bring it to England as a new and secret plan adapted to electrical signalling at a distance without wires. Being influentially introduced to the Chief Engineer of the Government Telegraphs, who presumably was too busy to remember what had recently been done in the Hertz-wave direction, the box was announced as containing a 'new plan' which had been 'brought to England'!

This barbed statement came from a scientist whose demonstration lecture at the Royal Institution in June 1894 on "The work of Hertz and some of his successors," widely reported throughout the scientific world, had, it is said, stimulated the young Marconi's interest in the subject of signalling without wires. (I am happy to record that despite this devastating early comment on the young Marconi by Oliver Lodge, they later became mutual admirers, so much so that twenty-five years later, at a meeting in London to honor Lodge's scientific achievements, Marconi generously described him as "one of our greatest physicists and thinkers," and added that "his pioneering in wireless should never be forgotten." In a book published about this time Lodge described Marconi's 1901 successful transatlantic experiment as "constituting an epoch in human history and an astonishing and remarkable feat.")

There can be little doubt that Marconi's family background and family connections had a great deal to do with the quite remarkable activity of this young man in 1896–1897. His mother was Irish, a daughter of the wealthy Jameson family of Irish whisky distillers. She had come to Bologna as a music student and in 1864 married a well-to-do businessman of independent means, a widower some seventeen years older than herself. Marconi thus grew up partly in Italy and partly in Britain, and spoke both Italian and English. In view of the large difference in age between his mother and father it is not surprising that his early career was greatly influenced by his mother, and it was his mother who accompanied him to Britain in February 1896 and secured for him an introduction to the Chief Engineer of the British Post Office. With their family connections in the business world of Britain, the immediate patenting of the apparatus "for telegraphy without wires" and the formation of a commercial enterprise for wireless telegraphy would not present undue difficulties for Signora Marconi and her son.

Without in any way detracting from Marconi's undoubted great personal gifts, his dedication and determination, the significance to his whole career of the commercial enterprise, established when he was only 23 and carrying his name, is not to be underestimated. The share capital of the Marconi Company, launched at £100,000 in 1897, was increased to £1,000,000 by 1911. In these fourteen years the Company established a commanding position in the world wireless business and in Britain and Canada it had a near monopoly. Marconi himself always had a clear appreciation of the commercial aspects of wireless telegraphy. Interviewed in 1933 in New York he is quoted as saying

> The money aspect of the development of radio must not be forgotten. For example my first experiment in wireless across the Atlantic cost more than $200,000. Governments are not so constituted that they can afford to encourage something which has not yet been proved worthwhile and a great deal of credit must be given to businessmen who had faith to put money into the development of wireless. Scientists cannot get along without money to back them.

Furthermore, from the start the Marconi Company sought and obtained the assistance of distinguished scientists and engineers as advisers and consultants. One of the most important of these was Ambrose Fleming (of thermionic valve fame), a former student of Clark Maxwell and later Professor of Electrical Engineering at University College, London. Fleming was engaged as a scientific adviser to the Marconi Company from 1899. He was 50 at the time and Marconi, 25. Fleming was closely involved with the design of the transmitter for the transatlantic experiment and was associated with Marconi throughout his life.

Facts such as these make it clear that much of the young Marconi's phenomenal personal success followed from his complete dedication to the job in hand, namely, the establishment of the new system of signalling without wires, a task from which no obstacle would discourage him. Marconi's early involvement with patents and with the commercial world is also typical of much of the subsequent history of wireless telegraphy, in which commercial interests and protracted legal arguments about patent rights loomed very large, even to the extent, on times, of influencing technological progress.

What, then, was the state of knowledge concerning radio waves and the ionosphere at the beginning of this century and more particularly what were the views of Marconi himself at this time about the way in which radio waves were propagated to considerable distances? An interesting record of his thoughts on this subject is provided by a series of five lectures which he gave to the Royal Institution in London at about two year intervals between 1900 and 1911. His lecture of 2 February 1900 (this was nearly two years before the transatlantic experiment) was entitled "Wireless telegraphy," and in referring to some transmission experiments which he had carried out in England over a sea path of 85 miles he noted that owing to the Earth's curvature there was between the transmitter and the receiver "a hill of water" (as he put it) 1000 feet high, and he commented,

> If those waves travelled only in straight lines the signals would not have been received except with a vertical wire 1000 feet high at both stations, so the curvature

of the Earth is apparently no obstacle to the transmission. . . . The Hertzian waves must either go over or round the dome of water or pass through it.

Marconi also expressed a similar opinion about transmission over land.

> Rock masses of very considerable size intervening between two stations do not in the least affect the freedom of communication by ether wave telegraphy.

It must, of course, be remembered that right from the start Marconi had a single-minded interest in the practical and commercial aspects of radio. He was concerned at all times to show that wireless telegraphy was a perfectly reliable means of long-distance communication which would supplement, if not indeed in due course perhaps supplant, communication by cable and he was clearly unwilling to contemplate that any obstacle, whether it be ocean or mountain, would stop these Hertzian waves getting through. Indeed sometimes his unshakable confidence in the ability of wireless waves to travel over ever-increasing distances (coupled incidentally with his low opinion of cable companies) resulted from time to time in some amusing and wry comments. Thus it seems that in 1899 Marconi had supplied some wireless equipment to the British War Office for use in the South African Boer War, but apparently when it was tried out in battle they failed to get any signals through. In the 1900 Royal Institution lecture Marconi, referring to this matter, had this to say:

> It has been reported that the difficulty of getting through from one station to another was due to iron in the hills. If this message had not been cabled from South Africa it would hardly be credible that anyone should have committed himself to such an unscientific opinion. As a matter of fact, iron would have no greater destructive effect on these Hertzian waves than any other metal, the rays getting very easily round or over such obstacles.

For Marconi it seems that nothing was going to be allowed to inhibit long-distance radio communication.

In June 1902 he again lectured at the Royal Institution, this time under the title "The progress of electric space telegraphy." This was some six months after his successful transatlantic experiments, and in discussing his results on transmissions from his station at Poldhu in Cornwall to a ship crossing the Atlantic to America he had this to say:

> . . . Another result of considerable scientific interest was that at distances of over 700 miles the signals transmitted during the day failed entirely, while those sent at night remained quite strong up to 1551 miles and were even decipherable up to a distance of 2099 miles.

Here, did he but know it, Marconi had obtained clear experimental evidence not only for long distance radio propagation by means of the ionosphere but for the day-to-night changes in the reflecting layer. However, the upper atmosphere ionized layer postulate came from others and Marconi chose to explain his results as probably due to the influence of daylight on his electrically charged transmitting aerial. In offering this explanation it now seems strange that Marconi did not at once enquire why for shorter-distance transmissions there was no apparent change from day to night in the efficiency of his transmitting aerial.

Anyway, after reporting this difference in reception conditions between day and night, Marconi immediately proceeded again to emphasize to his audience his unshakable faith in the future of transatlantic wireless, and once again he took the opportunity of another sly dig at his friends in the cable companies.

> I do not think that the effect of daylight will be to confine the working of transatlantic wireless telegraphy to the hours of darkness, as sufficient sending energy can be used during the daytime at the transmitting stations to make up for the loss of range of the signals, and therefore this business of communicating across the Atlantic will not be one of those works of darkness with which some people connected with cable companies would seem disposed to class it.

In the same year that Marconi gave that lecture (1902), Kennelly and Heaviside independently postulated the existence of an ionized layer in the Earth's atmosphere as the reflector of radio waves.

Marconi next lectured at the Royal Institution three years later and it is surprising to note that neither in this lecture of 1905 nor in a subsequent lecture given in 1908 did he make any reference at all to Kennelly or Heaviside, nor indeed to the series of papers which had appeared in 1902 and 1903 in the *Proceedings of the Royal Society* by Macdonald, Rayleigh, and Poincaré in which diffraction of radio waves around the curved surface of the Earth was discussed as a possible explanation of his own successful 1901 transatlantic experiment. The lecture of 1908 was specifically entitled "Transatlantic wireless telegraphy," and here one might certainly have expected some reference to one or other of these distinguished workers, but none at all was made. It is hard to believe that six years after the published papers of Kennelly and Heaviside their hypothesis had not come to his notice, and one must conclude that Marconi was not particularly interested in precisely how radio waves were transmitted from one point on the Earth to another but was concerned only with getting them there. His concern always was with the practical and commercial aspects of communication, with ways and means for improving reliability and of extending range.

Indeed in these early days of radio communication much of the excitement lay in achieving success over ever-increasing distances. In 1900 the maximum transmission distance achieved was about 100 miles and it has often been asked why, as a next step, did Marconi attempt transmission right across the Atlantic, a distance of 2000 miles or so. Marconi himself gave the answer to the question in his 1908 lecture in these words,

> I have often been asked why I did not first endeavour to establish commercial communication between places situated at a shorter distance. The answer is very simple. The cables which connect England to the continent and between most continental countries are government owned and these governments would not, and will not, allow the establishment of any system, wireless or otherwise, which might in any way tamper with the revenue derived from these cables. However, as regards transatlantic communication the conditions were different. There was no law either in Canada or the United States to impede the working of wireless telegraphy across the Atlantic.

A second reason which Marconi states prompted him to attempt communication was an economic one—he considered that it would be much more profitable to use wireless telegraphy over long distances than over short distances. Thus the reasons for the historic transatlantic experiment of 1901 were based more on commercial and economic rather than on scientific considerations and, unless he moved his experiments entirely out of western Europe, Marconi had, it seems, little choice but to attempt communication right across the Atlantic.

The historic signal transmitted across the Atlantic was of course simply the letter S (in Morse code, three dots). Asked why he chose the letter S Marconi replied that

> The switching arrangements at the sending station at Poldhu were not constructed at that time in such a manner as to withstand long periods of operation without considerable wear and tear—especially if letters containing dashes were sent.

Marconi gave a fifth lecture to the Royal Institution on 2 June 1911 under the title "Radiotelegraphy," his last to the Royal Institution in this early period of wireless telegraphy. By this time his Company has established a number of long-distance wireless telegraphy circuits and Marconi reported on some of the long-wave field strength data which had begun to accumulate. In particular he showed curves illustrating the diurnal variation in field strength over a distance of 3000 km on two very long wavelengths, 5000 and 7000 m (60 and 43 kHz). The data are qualitative rather than quantitative but the difference between day and night conditions and the distinct variations associated with sunrise and sunset at the two ends of the transmission path are clear.

MEDIUM AND LONG WAVE PROPAGATION 1901-1924

The historic experiments of Hertz in 1887 were carried out on a wavelength of about 30 cm and the experiments which Marconi demonstrated to the British Post Office engineers in 1896 were again on this sort of wavelength. However, just a few years later, attempts at wireless telegraphy over substantial distances were rapidly moving toward long and very long waves, hundreds and even thousands of meters long. The transatlantic experiment of 1901 was carried out on a medium-to-long wavelength, although there seems to be some difference of opinion about the actual wavelength of the transmissions. (This is not surprising since the spark transmitter undoubtedly radiated energy over a wide range of wavelengths.) Marconi himself in 1908 gave it as 1200 feet (370 m) but Fleming, who was involved in the design of the transmitter, stated that the wavelength was "certainly greater than 900 m." Mr. J. A. Ratcliffe, in a recent lecture to the IEE, estimated it as probably about 600 m. In the years following the transatlantic experiment the urge was for greater and greater signalling distances and most of the stations, particularly those on land, used wavelengths in the 1000 and 10000 meter range. The great driving force at the time was to have transmissions which would in some way get around the curved Earth, and as long as there was the feeling that radio waves were clinging to the surface of the Earth in some sort of sliding wave propagation, then clearly there seemed a better chance of success with very long wavelengths, even wavelengths comparable with the size of the Earth.

Even ten years after his 1901 experiment Marconi stated that "these (transatlantic) waves do not propagate in the same manner as free radiation from a classical Hertzian oscillator but instead glide along the surface of the Earth." The wireless communicators were also concerned of course to minimize the troublesome, if mysterious, difference between day and night transmission conditions. It is true that Kennelly and Heaviside postulated this reflecting layer, but reading the radio literature of this period one senses that few people took much notice of this hypothesis; the communication engineers led by Marconi seemed to say, 'maybe there is a kind of reflecting layer, but if so, its effect is more of a nuisance value than anything else and the thing to do is to get a stronger and stronger ground wave and one factor in achieving this is to use larger aerials and longer wavelengths.' Marconi, in various lectures given between 1902 and 1911, makes hardly any reference to the reflecting layer and, in fact, very few radio men of that time did. Even in July 1924, in reply to some discussion following a lecture at the Royal Society of Arts, Marconi is reported as saying that in regard to the Heaviside layer, there was perhaps no Heaviside layer. He (Marconi) did not want it, especially if it shifted its position! Without placing too much weight on this particular remark, I think there is more than a grain of truth in the statement that he did not want the Heaviside layer. He had after all, against all the odds, triumphed over the theoreticians and successfully coaxed his wireless waves to span vast distances; if at all possible he did not want any assistance for them, in their travel, from any ionized layer.

In the years following 1902, when Kennelly and Heaviside published their conducting layer hypotheses, there was little or no systematic attempt to follow up the idea, although some workers clearly gave further thought as to how such a layer might be formed and how it would operate. In 1912 W. H. Eccles published his theoretical analysis, giving expressions for the velocity and attenuation of electromagnetic waves propagated through a medium containing free electric charges, which he supposed to be charged ions of atomic mass. There were some too who speculated on the possible source of such ionization. Thus Ambrose Fleming, in 1917 in a lecture at the Royal Institution, discussed the possible ionization of oxygen in the high atmosphere by solar radiation in the wavelength range 1500 to 1800 Å. Gradually the undoubted existence of the Kennelly-Heaviside layer came to be accepted. In June 1917 on the occasion of the 21st anniversary of Marconi's 1896 patent, Fleming wrote:

> In spite of the fact that some mathematicians consider that diffraction alone will account for long distance telegraphy over 3000 to 6000 miles, it is pretty certain that three causes are combined in effecting it, namely, a surface electric wave propagation, a diffracted space wave, and refraction of the space wave by the upper levels of the terrestrial atmosphere. To disentangle these effects will need much large-scale experimenting on the lines of the excellent research by Dr. Austin and Mr. Hogan under the auspices of the U.S. Navy Department.

Further actual field strength experiments were, in fact, soon to be undertaken.

It was about the time of the Fleming lecture of 1909 that L. W. Austin in the States started his extensive set of field strength measurements which ultimately led to the famous Austin-Cohen empirical formula for the received field intensity. The Austin-Cohen formula was for many years the accepted standard against which measurements were compared and which indeed formed the basis for the design of transmitting stations.

In 1918 and 1919 G. N. Watson carried out two important theoretical analyses on radio wave propagation. The 1918 paper was concerned with pure diffraction of electromagnetic waves around a sphere, but the 1919 paper took into account the possible influence of a reflecting layer and considered the problem of diffraction between concentric conducting spheres.

In the period immediately after World War I, 1919 to 1920 or so, extensive tests were carried out over long distances by many authorities, including the French Admiralty, the British Admiralty, and the Marconi Company, to examine anew the propagation law over land and sea. All the experimental data showed conclusively that at great distances the Austin-Cohen formula yielded field strength too small by very large factors, but the data were in good agreement with the Watson 1919 formula for a wave diffracted around the Earth but confined between the surface and a conducting layer at a height of about 100 kilometers. The evidence for the influence of the Kennelly-Heaviside layer on long-wave long-distance radio propagation was now strong.

SHORT-WAVE PROPAGATION 1901-1924

As indicated in the preceding section, in the years following the 1901 transatlantic experiment the major interest was in wireless communication using long waves. However, it is interesting to note that even at this time the short wave bands were also being used. Thus Marconi, writing in 1924, had this to say:

> For a period of about eight years after 1901 the Marconi Company had installed on a considerable number of ships a system of spark transmitters utilizing waves of only 120 m in length. This system, although utilizing a very small amount of energy, was capable of regularly communicating over a distance of about 1000 miles although a comparatively insensitive tape receiver was employed.

Nevertheless, in the early 1900s the possibility of reliable long-distance communication on short waves was not actively pursued and short-wave propagation did not figure prominently on the radio stage for another twenty years.

Interest in the possibility of using short waves for long-distance communication began to revive immediately after World War I, just at the time that the Austin-Cohen field strength formula was being put to stringent experimental tests. Marconi himself gave a hint of his thinking at this time in a lecture which he gave in Birmingham in 1921.

> My contact with many phases of radiotelegraphy has lately given me the impression that so far as concerns long-distance communication, we have all rather got into a rut. I cannot help holding certain views which I hope to express soon before some scientific society [Evidently Marconi didn't consider this Birmingham audience suitable recipients for the good news—author] and those views lead me to believe that in the near future it will be possible to establish reliable transoceanic communication at great speeds, with a much smaller amount of energy than is now found necessary and with much simpler apparatus.

This cryptic remark was, of course, a veiled reference to the use of short waves.

During World War I the military requirement for secrecy had resulted in experiments on line-of-sight communication with short wavelengths. Marconi himself was at this time with the Italian forces and stated that early in 1916 he started experimenting on these wavelengths of a few meters. Immediately after the end of the war, with the demobilization of vast numbers of enthusiastic wireless operators, the boom in long-distance short-wave communications soon began. In the USA large numbers of amateur wireless stations were soon established despite the restriction placed on their activities by the government, limiting them to transmissions on 200 meters. These amateurs quickly established among themselves a system of relay communication across the continent of America and in 1920 they prepared for an attempt at transatlantic communication. The first tests in February 1921 were unsuccessful but a further series of tests the following December were highly successful, in fact the first complete message was transmitted and received by amateurs on short waves across the Atlantic on 12 December 1921, twenty years to the day after Marconi's pioneer experiment. The wavelength used was 200 meters (1.5 MHz)—not exactly an optimum working frequency for this path, but the only one officially permitted to them.

In this period Marconi and his associates Franklin and Round were also experimenting on short waves. In 1919 Franklin used valves to generate short waves. He carried out tests on a wavelength of 73 meters and the signals were picked up in Australia. In the period April-June 1923 Marconi himself carried out systematic tests on 100 meters on his yacht *Elettra*, travelling between England and the Cape Verde Islands (3500 km). His transmitter at Poldhu was, it is said, capable of radiating a power of 120 kw in the required direction but Marconi found that even when the power was reduced to 1 kw the signals received at the Cape Verde Islands "were still stronger than would have been necessary for carrying out commercial work over that distance." He also added that calculation showed that at night signals would still have been readable with a radiated power of only 1/10 kw. Marconi was quick to see the tremendous advantages of short waves over long waves for commercial long-distance communication. At these wavelengths, beaming of the energy in the required direction was an easy matter, signalling could be carried out much faster, and the whole equipment cost only a fraction of that required for long-wave work. It is interesting to note that at the very same time he was carrying out these long-distance tests on short waves, tests of the accuracy of the Austin-Cohen formula were being made over long-distance paths on wavelengths of thousands of meters by various governments and also by the Marconi Company itself. Clearly these were the years of transition, with further extensive studies of long-distance communication using the well-established long waves, coexisting with the exciting new possibilities of doing the same job with short waves with greater efficiency and at a fraction of the cost.

THE IONOSPHERE 1924–1932

On the evening of Thursday, 11 December 1924, Marconi gave his inaugural lecture in London as President of the Royal Society of Arts and made the remark, "It is my belief that the whole theory and practice of long-distance wireless communication is just now undergoing a most important and radical change." Little did he know that on that very same Thursday evening, indeed perhaps at that very hour, Appleton and Barnett were on their way to Oxford to set up the receiving equipment for their historic experiment to be carried out on the following night.

Marconi went on to refer to the hypothesis which had been put forward for a reflecting layer in the upper atmosphere and concluded this part of his lecture with the statement,

> These theories and hypotheses, together with others that I have not referred to, have never satisfactorily explained to my mind why waves of certain lengths will cover great distances whilst others will only cover similar ranges at night times.

Once again, little did he know that 24 hours later a crucial experiment would be made which would make such matters clear and in fact would indeed initiate the "era of the ionosphere."

The large-scale Lloyd's mirror type experiment successfully carried out by Appleton and Barnett in December 1924 is well known and need not be described here. It is sufficient to note that once again did a radio experiment carried out on the night of 12 December triumph. (Marconi's transatlantic experiment of 1901 was carried out on 12 December, the first message transmitted by amateurs was received across the Atlantic on 12 December 1921, and the existence of the ionosphere was finally established by Appleton on 12 December 1924.)

Appleton and Barnett's initial experiment was still carried out at a medium wavelength (400 m) but in the next year or so they too moved to shorter wavelengths and about two years later discovered that there was a second layer of much denser ionization above the Kennelly-Heaviside layer. In 1926 Breit and Tuve published details of the pulse technique which was soon to become the standard technique for radio sounding of the ionosphere. Thus, by early 1927 the two central strata of the ionosphere, later designated by Appleton the *E* and *F* layers, were established, an ingenious simple radio sounding technique had been invented, and the stage was set for the "huge field of investigation" which Appleton had predicted in a letter to van der Pol on 1 January 1925.

On the theoretical side, Larmor in 1924, just prior to the Appleton-Barnett experiment, had reconsidered refraction of electromagnetic waves in a dielectric medium containing a moderate density of electrons and showed that radio waves incident on such a medium would be gradually refracted back toward the Earth and that an electron density of as small as 1 electron per cubic centimeter would be sufficient to bend a 1000 m wave to the curvature of the Earth. The possible influence of the Earth's magnetic field on ionospheric propagation was quickly recognized by Appleton (1925) and by Nichols and Schelleng (1925) in the USA. Contributions to the theory were also made by other workers, including Taylor and Hulburt (1926) and Lassen (1926). Expressions for the refractive index of an ionized medium for longitudinal and transverse propagation had been published in 1909 by H. A. Lorentz and in 1927 Appleton extended the theory to cover propagation in other directions and include the effect of collisions. Other contributions were made by Goldstein (1928) and Hartree (1931). In 1932 Appleton published his full magnetoionic theory.

Theoretical work on the formation of ionized strata in the upper atmosphere was carried out by Hulburt (1928) and in 1931, Sydney Chapman published his famous paper on "The absorption, dissociative or ionizing effect of solar monochromatic radiation on the Earth's upper atmosphere," a work which, in one form or another, has to this day remained fundamental to our understanding of the ionosphere.

Marconi's contribution to and involvement with ionospheric radio wave propagation really came to an end in the middle and late twenties soon after the establishment of the short-wave beam stations. In 1927 he had a serious illness which was diagnosed as angina and, although he recovered well from this attack, the heart complaint must to some extent have shadowed his remaining ten years. In the early thirties, just when so many were vigorously taking up radio studies of the ionosphere, he turned his attention once again to the use of centimeter wavelengths for propagation, navigation, and indeed for detection purposes. As with his pioneer experiments of thirty years earlier, on the propagation side one of his objectives was to achieve reliable communication well beyond the optical horizon, and thus again confound the theoreticians, and of course in this he again had considerable success.

CONCLUSION

The history of radio wave propagation experiments and of the ionosphere will, for all time, be respectively linked with two famous names in radio science, Marconi and Appleton. In this lecture I have confined myself to the contribution of one whose birth we are commemorating. I was never privileged to meet Marconi but Appleton I knew intimately for some 27 years and one of my earliest radio memories is the tribute which I heard Appleton broadcast on 20 July 1937, the day that Marconi died. Here, by way of conclusion, is an extract from that radio broadcast tribute.

> The work of the Marchese Marconi has played a vitally important part in the development of wireless communications and broadcasting as we know it today. But substantial as is the list of his scientific and technical achievements, the man has been as great as his work. . . . He realized from the first that the full potentials of electric wave communication would not be exploited until the world could be spanned and to this end he directed his efforts. In 1901 Marconi first succeeded in sending signals across the Atlantic Ocean. This was an achievement of outstanding and technical importance. There was much in the way of theory to deter anyone contemplating such an experiment. But Marconi, a true experimenter, was not to be deterred by theories. No outlook was too unpromising for Marconi. There was for him no finality in any branch of the subject. For over forty years he worked as a radio experimenter with unflagging energy and enthusiasm and great as his own achievements have been he has never been content to rest. For him we were always at the beginning of things. . . . What then was the secret of his quite unique success? This, I think: that he was never daunted by an unpromising situation and if difficulties seemed to be ahead he tackled them with the zeal of a young experimenter beginning his research. He was like this to the end.

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