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Marconi centenary

Annual Report

IEA preview

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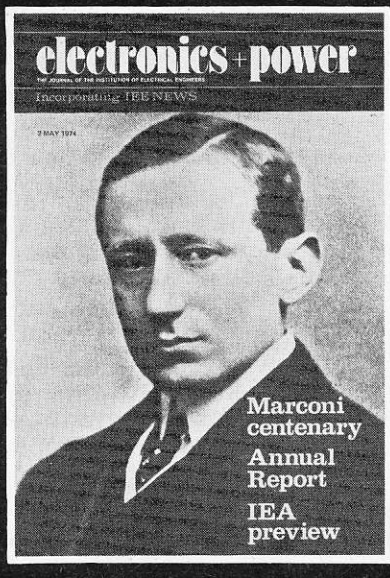
CONTENTS



COVER

On the 25th April 1974, engineers throughout the world celebrated the centenary of the birth of Guglielmo Marconi. Our cover picture was taken in 1909

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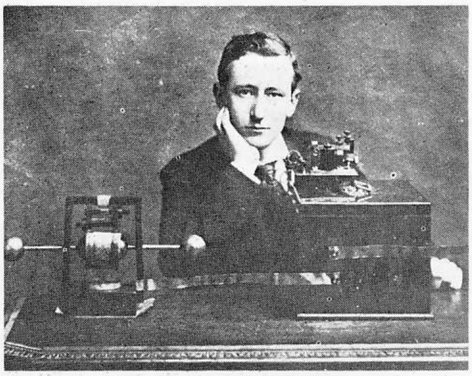
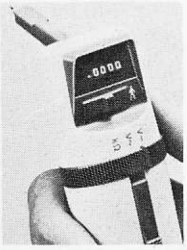
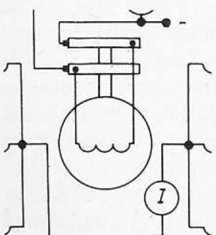
IN THIS ISSUE

What was Marconi like? What were the factors that influenced his early life? What were the events leading up to that first historic transatlantic broadcast? And what did Marconi do in the 1920s and 1930s? These are some of the questions that we endeavour to answer in five articles especially written for *Electronics & Power*. The first article (p.308) introduces us to Marconi, and then follow two historical accounts of Marconi's life and achievements, one covering the period 1874-1919 (p.312) and the second the later years from 1919 to Marconi's death in 1937 (p.315). On p.320 we read of reactions from others to Marconi's work, and conclude on p.323 with a more detailed account of the trials at Lavernock in 1897.





The field of electronic instrumentation is a fast-moving one, especially since the advent of micro-miniaturisation and complex integrated circuits. On p.327, David Metcalfe reviews recent progress in electronic instrumentation, and on p.332 we preview the IEA exhibition, Britain's premier instrument show.



One of the vital parameters for any electrical machine is its thermal performance, and ways are always being investigated for developing synthetic temperature tests. Two new tests have recently been developed at the University of Bristol which deal with a.c. machines (p.329).

NEXT ISSUE

The next issue of *Electronics & Power* will be published on the 16th May and will include articles on solar power, high-voltage transformers and developments in medical ultrasonics diagnostics.

FOCUS

MARCONI – father of the radio age

The 25th April 1974 marked the centenary of the birth of Guglielmo Marconi. It would be an impossible task for us here to assess in a few lines the contribution made by Marconi in the field of radio communication. Suffice it to say that he will be remembered and honoured for ever for his unique talents, his perseverence, his drive and his many experimental 'firsts'.

A joint meeting of the IEE Electronics Division and the IERE entitled 'The Marconi heritage' was held at Savoy Place on the 25th April to celebrate the centenary, and some of Marconi's successors, each of whom has achieved fame in that same branch of engineering science, gathered to pay tribute to the great man. In this issue, we publish several articles, based on lectures given at that meeting, which describe Marconi's innovations, and which give contemporary reactions to his pioneering work.

We read of the progress that was made between 1894 and 1937. Sir Eric Eastwood writes 'He had commenced his work with a vision: to achieve comprehensive communication with the aid of Hertz's waves; by the end he had spanned the Atlantic. Marconi was a true engineer, who systematically developed his *system* to meet a communication need. From his work much pure science has stemmed, including knowledge of the Earth's atmosphere and its interation with solar radiation. But Marconi was primarily a wireless-communication engineer. His work initiated the radio age.'

Prof. Jolly tells us: 'Marconi was an innovator rather than a discoverer. It was the ability to select, modify, and organise scientific discovery, people and, indeed, events, which brought Marconi to his great achievement and his world fame. His distinguished "competitors" were more interested in the fundamental properties of Hertzian waves. Marconi had no interest in these fundamental properties, but he had an indomitable will to succeed in his clear-cut task of increasing the range of signals, and he brought to this task the endless patience needed to try all likely, and some very unlikely, experimental modifications.'

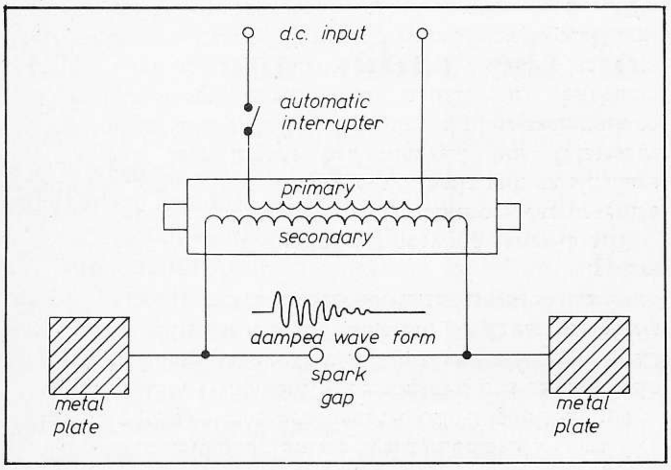
Perhaps the most apt description of Marconi comes from G. A. Isted who reports: 'He had a remarkable gift of invention and experimentation. He had, in fact, what one might term "wireless greenfingers"'.

Our tribute to Marconi will be completed in the 30th May issue. Two further articles will describe modern developments in global and maritime communication which stem from Marconi's early developments.

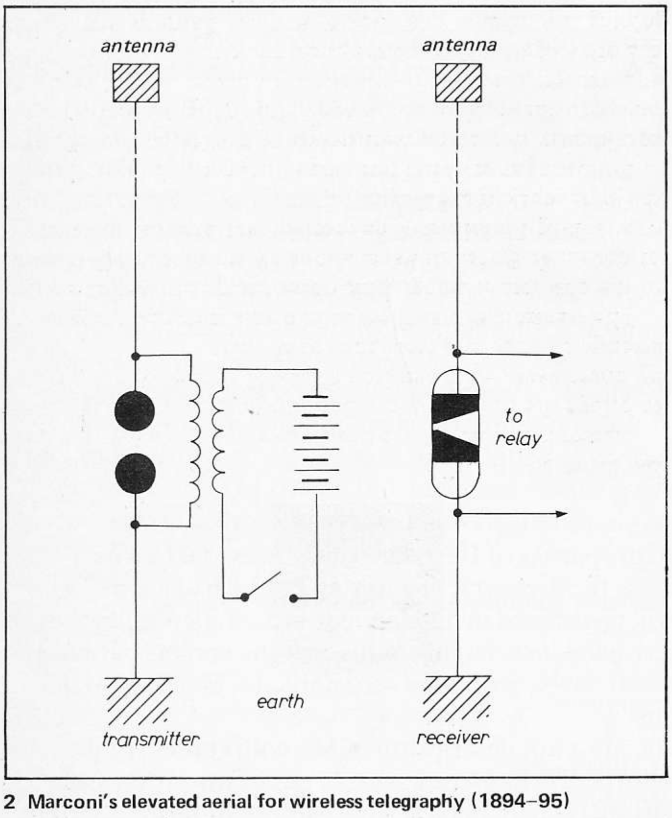
MARCONI

pioneer of wireless telegraphy

by SIR ERIC EASTWOOD
Ph.D., F.Inst.P., C.Eng., F.I.E.E., F.R.S.



1 Hertz's generator of electromagnetic waves



2 Marconi's elevated aerial for wireless telegraphy (1894–95)

Sir Eric Eastwood is chief scientist with the Marconi Co. and director of research, GEC. He is immediate Past-President of the IEE

This article is based on a lecture delivered to a joint meeting of the IEE Electronics Division and the IERE at Savoy Place on the 25th April 1974 to mark the centenary of the birth of Guglielmo Marconi.

Guglielmo Marconi was born on the 25th April 1874. At that time, Heinrich Hertz was a young student of 17, and nine years had passed since Maxwell published his famous paper on electromagnetic theory.

Propagation of waves against action at a distance

When we look back 100 years, it is rather difficult for us to appreciate the shock which the Faraday/Maxwell theory of the electromagnetic field had given to the world of physics. This theory had replaced the view of electric and magnetic interactions as action-at-a-distance phenomena by the concept that all such effects are propagated with finite velocity through the air, through space, or indeed through any insulating medium; but the theory still lacked direct experimental confirmation.

The success of Newton's theory of gravitation had made scientists less adherent to the old philosophical axiom that matter cannot act where it is not, and so gravitation as a paradigm of all action-at-a-distance phenomena became not merely acceptable but was regarded as 'natural'. Thus the zeal of the disciples exceeded that of Newton himself, who, in 1692 wrote: 'That gravity should be innate, inherent, and essential to matter, so that one body may act upon another at a distance through a vacuum without the mediation of anything else, by and through which their action and force may be conveyed from one to another, is to me so great an absurdity that I believe no man who has in philosophical matters a competent faculty of thinking can ever fall into it'.[1]

Faraday had weakened the action at a distance idea, but the elimination was completed by Maxwell's mathematical formulation of Faraday's fields of force, which led to his famous equations and the conclusion that electromagnetic disturbances were propagated with finite velocity. It seems incredible to us now that over 20 years were to elapse before the Maxwell/Faraday view was generally accepted and the way made clear for examination of the consequences of the theory, as in Einstein's work, or for practical applications as executed by Marconi and the communicators. Perhaps a better appreciation of the confused thoughts about these matters which existed 100 years ago may be gained by considering the subject of gravity waves at the present time. It was pointed out by Einstein in 1916 that the equations of his general theory of relativity suggested that gravity waves might well be propagated from a centre of disturbance such as a stellar explosion, but this idea had attracted little attention. A theory may be ignored, but experiments cannot be set aside so lightly; and so, when Prof. Weber of the University of Maryland claimed in 1969 that he had detected such waves emanating from the centre of our galaxy, the world of physics was disturbed. A great deal of ingenuity has since been applied to develop very sensitive instruments that would confirm or disprove Weber's claim. If it be proved, then one of the last strongholds of action at a distance would have finally fallen to experimental demonstration.

Hertz and electromagnetic waves

The seekers after gravitational radiation are in the difficult position that they cannot control the radiation process. They can work only to perfect their receivers and try to detect the radiation which Nature may have provided for them. When Hertz in 1887 decided to tackle the corresponding problem of demonstrating experimentally that the properties of the electromagnetic field were as described by Maxwell, he had at least both the transmitter and receiver of the presumed waves under his control. He was well aware of the oscillatory nature of the discharge from a Leyden jar, by reason of the work of Helmholtz, Kelvin and Fedderson, also of the theoretical possibility of increasing the frequency of the oscillation by the use of 'open wire circuits of good conductivity provided that the ends are not loaded with large capacities', and so he used as his generator of electromagnetic waves a large Ruhmkorff coil across the terminals of which he placed a 'discharger', i.e. a spark gap, separating two linear conductors. This is the arrangement which we now appropriately term a Hertzian oscillator (Fig. 1).

His receiver consisted simply of a single loop of stiff wire broken by a small adjustable spark gap, but this circuit could be tuned to resonate with the transmitter and he observed the

MARCONI CENTENARY

feeble sparks in a darkened room! Hertz's experiments were first performed with radiation having a wavelength of the order of 5 m, but later he deliberately reduced this to 30 cm to avoid effects from interactions with the walls of his laboratory. With these simple devices, he was able to distinguish between the induction field and the radiation field created by the oscillator and to show that an electromagnetic disturbance was indeed propagated through the air with a finite velocity approximately equal to that of light. He concluded, 'By these experiments the propagation in time of a supposed action-at-a-distance is for the first time proved'. Hertz's proof included 'a recognition of the fact that the electric forces can disentangle themselves from material bodies, and can continue to subsist as conditions or changes in the state of space.'.[2]

By means of his 30 cm apparatus, Hertz created 'rays' by locating his linear oscillator along the focal lines of a parabolic cylindrical reflector, and was able to demonstrate therewith the reflection, refraction and polarisation of his radiations precisely as with light waves. Thus he was able to claim that his experiments had made 'highly probable the hypothesis that light is an electrical phenomenon'. He added 'to give a strict proof of this hypothesis would logically require experiments upon light itself'. I am sure that Hertz would have been highly delighted to see the electrical breakdown of air which can now be produced by the beam from a modern high-power carbon-dioxide laser.

It was a tragic loss to science when Hertz died in 1894 at the early age of 37, but even by 1890 his electromagnetic investigations were complete and provided the experimental complement to Maxwell's theoretical studies. Hertz's contribution was vital for, as he himself wrote in 1893 only shortly before his death, 'as long as Maxwell's theory depended solely upon the probability of its results and not on the certainty of its hypotheses, it could not completely displace the theories which were opposed to it . . . the result of these experiments is to confirm the fundamental hypotheses of the Faraday/ Maxwell theory'.[2]

In Hertz's laboratory, the maximum distance between receiving loop and oscillator was 20 m; he made no attempt to extend the range of detection. His purpose was to investigate phenomena and not to signal information; but it will be seen that the time was now ripe for the application of electromagnetic waves to communication purposes, and this is what Marconi achieved.

Telegraphy without wires—Marconi

Augusto Righi, professor of physics at the University of Bologna, also experimented with electromagnetic waves and among other achievements made improvements to Hertz's oscillator. It was he who, in 1894, after the death of Hertz, wrote an appreciation of his electromagnetic researches, and this article profoundly influenced the young Marconi who was already attracted to electrical science. Probably the reading of this article was only one contributory factor which led Marconi to conceive the idea that Hertzian waves could be used to signal between remote stations. Marconi was as patient and dedicated as Hertz, but his aims were different: how to increase the signalling range and the reliability of the basic system which Hertz had devised.

During 1894, Marconi acquired, or built, equipment which permitted him to repeat some of Hertz's experiments and to acquire experience in the use of this somewhat temperamental gear. He recognised that the simple loop-and-spark receiver was the weak element of the system that should first be improved.

3 The young Marconi photographed shortly after his arrival in England in 1896 [Marconi Co.]

It was known from the work of a number of scientists, but particularly of Prof. Branly of Paris, that the conductivity of mixtures of certain metallic powders was increased by proximity to a spark discharge, even that produced between the contacts of an electric bell, but the high resistance could be restored after cessation of the spark by mechanically tapping the tube. This device was named the 'coherer' by Sir Oliver Lodge. It was greatly improved by Marconi who also combined with it a de-coherer, or tapper, which was activated by the relay/Morse printer circuit, so that after reception of the burst of damped waves radiated during each spark at the transmitter the coherer was restored to the high resistance condition. With this coherer, useful increase of signalling range was obtained, but substantial improvement came only with Marconi's discovery, during the summer of 1895, of the importance of an elevated radiator, or aerial. He found that, if one side of his oscillator were connected to a raised conductor and the other pole connected to earth, ranges of over 1 km were obtained using a receiver connected to an identical aerial/earth arrangement (Fig. 2). He also made the significant observation that, even when his receiver was screened from direct view of the transmitter by a small hill, nevertheless signals were still received.

A reliable range of 1 or 2 km independent of the terrain meant that Marconi was within sight of a practical military or commercial communication system. He accordingly offered his invention to the Italian Ministry of Posts & Telegraphs, but it was not accepted, and so he turned to London, seeking first sponsorship for the technical advancement of his system and,

MARCONI CENTENARY

secondly, opportunity to create a commercial company that would design, build and operate commercial wireless systems on a world scale—no less.

Marconi was only 22 years of age when he was granted the opportunity to describe his work to W. H. Preece, chief engineer of the GPO, and demonstrations were given in June 1896 (Fig. 3). In September of that year, we find him as a protégé of Preece demonstrating his system on Salisbury Plain, not only to engineers of the Post Office but also to representatives of the British Army and Navy. Both transmitter oscillator and receiver coherer used horizontal, parabolic reflectors; the wavelength was of the order of 30 cm and the signalling distance was about 3 km. Demonstrations were given on the same location some six months later, but now the reflectors were abandoned and the elevated aerial plus earth connection was employed to yield ranges of 7·5 km. This apparatus change was highly significant, for it marked the departure from decimetric wavelengths towards ever longer and longer waves. Many years were to pass before short waves were recognised as serious contenders for a place in national and international communication systems.

Throughout this first vital 12 months in London, Marconi owned much to Preece's support which culminated in the Bristol Channel tests of May 1897 when 13·9 km over water were successfully bridged (Fig. 4). In the following month, on the 4th June 1897, Preece delivered a Friday evening discourse to The Royal Institution with the title 'Signalling through space without wires'. In this address, he paid handsome tribute to Marconi's work and concluded with the statement:

'It has been said that Mr. Marconi has done nothing new. He has not discovered any new rays; his transmitter is comparatively old; his receiver is based on Branly's coherer. Columbus did not invent the egg, but he showed how to make it stand on its end, and Marconi has produced from known means a new electric eye more delicate than any known electrical instrument, and a new system of telegraphy that will reach places hitherto inaccessible. There are a great many practical points connected with this system that require to be threshed out in a practical manner before it can be placed on the market, but enough has been done to prove its value and to show that for shipping and lighthouse purposes, it will be a great and valuable acquisition'.[3]

Maritime application of his telegraphy system certainly accorded with Marconi's own views, but his ambitions were not to be limited to this field of operation only; on the 20th July 1897 the Marconi Co. was formed and relationships with Preece and the Post Office became rather less close!

Development progress 1897 - 1902

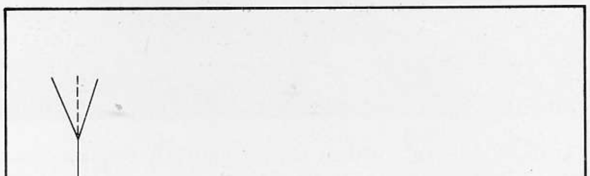
When Marconi arrived in England in February 1896, his first task was to safeguard his work by taking out a patent which was filed on the 2nd June 1896. The complete specification was accepted on the 2nd July 1897 (No. 12 039) and immediately defines the function his invention was intended to subserve:

'My invention relates to the transmission of signals by means of electrical oscillations of high frequency, which are set up in space or in conductors'.[4]

In the text which followed, emphasis was laid on the short-wave version of Hertz's oscillator with the discharger located along the focal line of a horizontal cylindrical parabolic reflector, while the discussion of the receiver stressed the mode of construction of the coherer in order to make it reliable. Of the 19 clauses in the patent, no less than 13 were concerned with the receiver, while the all-important claims on the elevated aerial/earth configuration for the transmitter and receiver were dealt with in two claims only and were to be applied in 'situations where obstacles such as many houses or a hill or mountains intervened between the transmitter and receiver'. Special mention was made of the use of aerials suspended by poles, balloons or kites.

On the 2nd March 1899, Marconi read his first paper to the Institution of Electrical Engineers on 'Wireless telegraphy.'[5] In this paper, he states clearly the importance of the vertical

4 Post Office engineers examining Marconi's apparatus which he used in 1897 for experiments across the Bristol Channel [Marconi Co.]



5 Marconi's 'syntonised' transmitter of the 'four sevens' patent (1900)

MARCONI CENTENARY

aerial and quotes from a letter he had sent to Preece in November 1896:

'. . . a radiator of Hertzian type having one pole earthed and the other connnected to a vertical, or almost vertical, conductor, or to a lofty capacity area, and a resonator consisting of a suitable receiver having similarly one terminal connected to earth and the other to an insulated vertical conductor, constitute a system of transmitter and receiver capable of giving effects at far greater distances than the ordinary systems of Hertz radiators and resonators'.

Understanding of the radiation process from such an aerial was very vague, but Marconi arrived empirically at a useful relationship connecting signalling distance and height of the radiator. He also recognised that such an aerial possessed no directivity and so would be vulnerable to interference. But his paramount need was to increase the signalling distance in spite of his lack of transmitter power and receiver sensitivity, and so the vertical aerial technique prevailed.

Marconi described the many successful demonstrations given during 1898, even to the Queen herself, also to Lord Kelvin, and he concluded his paper with the news that the French Government had just agreed to provide facilities for demonstration of a cross Channel link. A few days after the IEE meeting, the first wireless messages were transmitted betwen Dover and Boulogne.

The extent and variety of this demonstration work and the technical success achieved would suggest that Marconi's system of wireless telegraphy was gaining widespread acceptance and that the prosperity of his new company was assured. Unfortunately this was not quite the case; the first major order for equipment for the British Fleet was not placed by the Admiralty until July 1900 and this after the very successful use of the Marconi system during the Fleet manoeuvres of the previous summer. Commercial shipping lines were reluctant to install a system which still suffered from a number of operational weaknesses. Marconi was well aware that the fatal defect of the system was lack of selectivity and in his IEE paper of 1899 he stated:

'It is possible by means of syntonising arrangements, to prevent, to a certain extent, messages affecting systems or receivers for which they are not intended, and therefore to select any receiver by altering the wavelength of the transmitter'.

At that time Marconi almost seemed to think that only directive aerials could provide complete protection against interference; nevertheless, he was working intensively on the problem and exploring with his staff a variety of circuit tuning arrangements. Tuning for resonance between coupled circuits was fully appreciated and practised by Marconi from the very commmencement of his work, for it had been employed by both Hertz and Lodge. The problem facing Marconi was how to create a sharply tuned oscillator circuit that would still possess good radiating properties. His solution was to separate the two functions of frequency determination and radiation; he achieved this by tuning both the oscillator circuit and the aerial to a common frequency as he states quite precisely in Claim No. 3 of his famous 'Four sevens' patent taken out on the 26th April 1900:[6]

'A receiver of electric wave telegraphy in which both the transmitter and receiver contain a transformer, one circuit of which is a persistent oscillator and the other a good radiator or absorber of electric oscillations, all four circuits having the same time period or being harmonics of each other substantially as described' (Fig. 5).

This patent removed the major defect in Marconi's telegraph system and so provided the basis for a truly commercial wireless-telegraphy service, whether for maritime or land use; it did not, of course, describe means whereby the power of the transmitter could be increased, but this was also essential if signalling over really long distances were to be possible.

But could such long distances arise in practice? Wireless waves being identical with light waves must surely propagate tangentially to the Earth's surface after leaving the aerial and so be lost in space. This was the view of most scientists, but Marconi thought otherwise and had some useful evidence to support his view. Thus, in a discourse which he gave to The Royal Institution on the 2nd February 1900, he stressed as one of the most important technical results to have emerged from his participation in the naval manoeuvres of 1899:

'. . . . . the curvature of the Earth which intervened, however great the distance attained, was apparently no obstacle to the transmission. . . the Hertzian waves had either to go over or round the dome of water 530ft higher than the tops of the masts, or to pass through it, which latter course I believe would be impossible'.[7]

Fortified with his conviction that wireless waves were in some way bound to the Earth's surface, Marconi had every incentive, both commercial and technical, for seeking to increase substantially the powers of his transmitters, for only by long-distance signalling could wireless telegraphy be freed from the restrictions imposed by the monopolistic national telegraph services. Thus the real engineering phase of commerical wireless telegraphy had commenced. He chose the transatlantic link as his major target, and he achieved success in what must be one of the major scientific gambles of all time. Whether this success was first achieved in December 1901 as he himself believed, or demonstrated with certainty two months later aboard the *Philadelphia*, is a matter for speculation. Marconi himself did not regard it as a gamble, as is shown very clearly in the discourse which he gave to The Royal Institution in June 1902, when he presented a vivid description of the hazards of this famous experiment, not forgetting to pay generous testimony to the work of his helpers, including, significantly, Dr. J. A. Fleming of University College.[8]

Retrospect

The progress achieved by Marconi from 1894 to 1902 was amazing. He commenced his work with a vision: to achieve comprehensive communication systems with the aid of Hertz's waves; by the end of this period he had spanned the Atlantic. Marconi was a true engineer, who systematically developed his *system* to meet a communication need. His discovery of the vertical aerial, the move towards longer wavelengths, and his application of tuning to achieve selectivity were crucial steps to success during the first period of development before the invention of the thermionic valve.

From his work much pure science has stemmed, including knowledge of the structure of the Earth's atmosphere and its interaction with solar radiation. But Marconi was primarily a wireless-communication engineer, and it is for his outstanding achievements in this field that we honour the centenary of his birth. His work initiated the radio age. Since that time, wireless transmissions have been made continuously except for one brief interval of radio silence on the evening of the 20th July 1937, when the whole world paid tribute to the great pioneer of wireless who had just passed away.

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MARCONI

the making of the man

by Prof. W.P. JOLLY, B.Sc., C.Eng., F.I.E.E.

The historic events of Marconi's life are well known. But what of his early years—the years that shaped his character and gave him the will, the confidence and the skill to overcome the strongly entrenched opposition from scientists, businessmen and politicians?

Marconi was an innovator rather than a discoverer, and should the reader believe this to be a lesser role, he should remember that Marconi colonised territory that the explorers said did not exist. It was, above all, the ability to select, modify, and organise scientific discovery, people, and indeed events, which brought Marconi to his great achievements and his world fame.

Marconi's very early life was unusual and unsettled. He was born in 1874 in his father's town house at Bologna, but his childhood Italian home was Villa Grifone, the family estate just outside the town. His mother was an Irish girl who had eloped with Giuseppe Marconi, an Italian widower, much older than herself.

The inevitable ambivalence produced in his early life by this mixed Italian-Irish background was accentuated because his parents' interests diverged, and young Guglielmo spent long periods, sometimes years, away from his home on visits to Britian and homes of the English-speaking friends in Italy with his mother. During this roving infancy, the boy's formal education was fitfully managed by his mother or a private tutor. By the time he was eventually sent regularly to school in Florence he was neither amenable to the give and take of community life in the classroom, nor could he keep up with his fellow pupils, many of whom jeered at his poor Italian accent.

Entrance examination

It was a great disappointment to Marconi when he failed to pass the entrance examination of the Italian Naval Academy. He was very fond of the sea and had set his heart on becoming an officer in the Regia Marina. His stern old father was more than disappointed, he was angry. He considered that the boy had not applied himself to his studies and had frittered away the chance of a naval career.

Prof. Jolly is with the department of electrical & electronic engineering, King's College, University of London

Marconi had always been a rather solitary child, occupying himself at Villa Grifone with reading and building mechanical models and scientific toys. After he failed his naval entrance examination, he was sent to the Leghorn Technical Institute where he received with enthusiasm an introduction to formal scientific training. He devoted all his available time to physics and chemistry, spent his pocketmoney on equipment for experiments at home, and persuaded his parents to pay for private lessons in electricity from a Prof. Rosa.

But failure once again dogged Marconi. His ambition to take up a recognised course leading to a scientific career was thwarted when he was unable to pass the matriculation examination of Bologna University. His father became even more disgruntled with the boy, and his irritation was increased by seeing his son, now nearly twenty, apparently aimlessly wasting his time and money on experimental dabbling—abetted by his mother.

Marconi became more estranged from his father and drew even closer to his mother, who did everything she could to encourage her son in his efforts to make some sort of career out of electricity. She went to Prof. Righi, a famous 'electrician' who was a neighbour, and persuaded him to allow her son unofficially to attend the laboratory classes he gave in the department of physics in the University of Bologna. Of all the help his mother gave him this particular piece of 'string pulling' was vital to his subsequent career. Righi was interested in Hertzian waves, and the fundamental electricity taught in his department reflected this interest.

Obituary

In the summer of 1894, Marconi, on holiday, read the obituary of Hertz, who had died in the previous January. The description of Hertz's transmission of electromagnetic waves across a room inspired Marconi with an all consuming ambition to use them as the basis for a commercial telegraph communication system. He came back to Villa Grifone, shut himself up in two attics, which his mother had cleared to make a laboratory for him, and with single-minded dedication amounting to obsession he worked long, long hours to repeat Hertz's experiments.

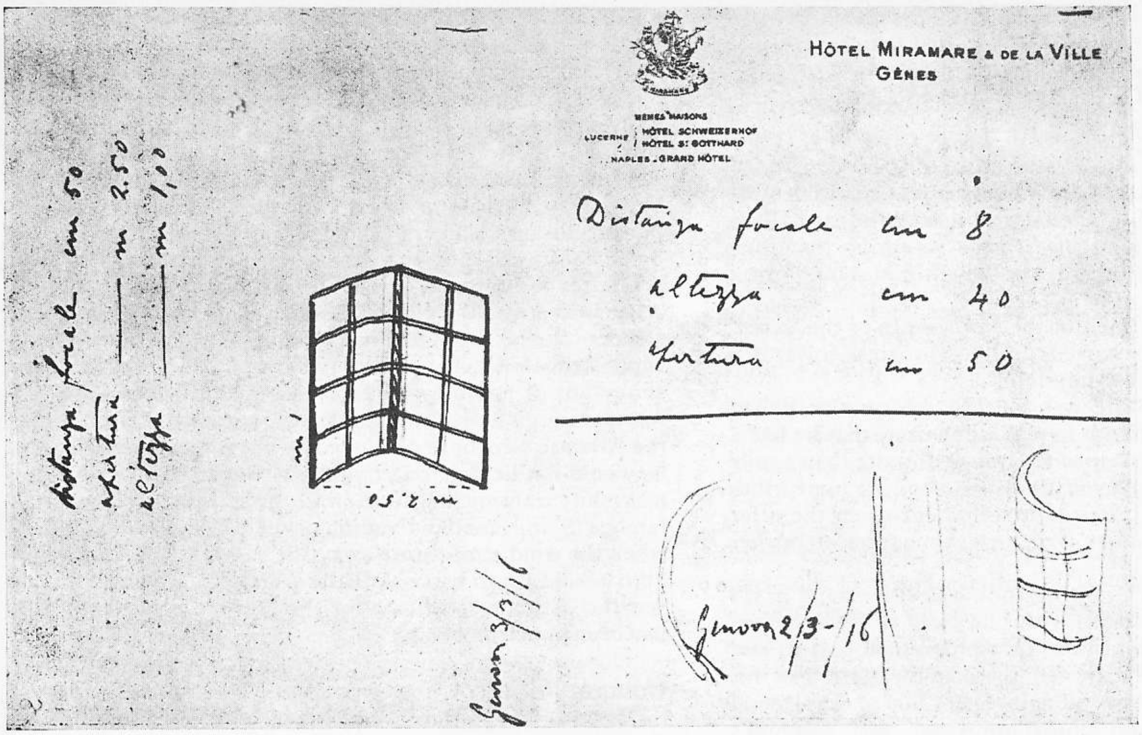
Throughout that winter, and the spring of 1895, Marconi diligently read in the university library all he could find about Hertz's work and the extensions of it carried out by Lodge in England, Bose in India, and Righi himself in Italy. Meticulously he assembled copies of their apparatus and tried to repeat the experiments; in particular, to increase the distance between the transmitting spark gap and the receiver. He was tortured by the thought that these experienced and distinguished scientists had all got several years start on him, and he worried incessantly that he would hear an announcement that one of them had produced a telegraph system.

But his distinguished 'competitors' were more interested in the fundamental properties of Hertzian waves and in demonstrating that, like light waves, their relations in the electromagnetic family, they underwent reflection, refraction, interference etc. Marconi had no interest in these fundamental properties; indeed his theoretical knowledge was quite inadequate to understand them. But he had an indomitable will to succeed in his clear-cut task of increasing the range of signals, and he brought to this task the endless patience needed to try all likely, and some very unlikely, experimental modifications. He also possessed a high degree of manual skill and sensitivity, which he exploited fully in making and improving the delicate apparatus of those first days of radio.

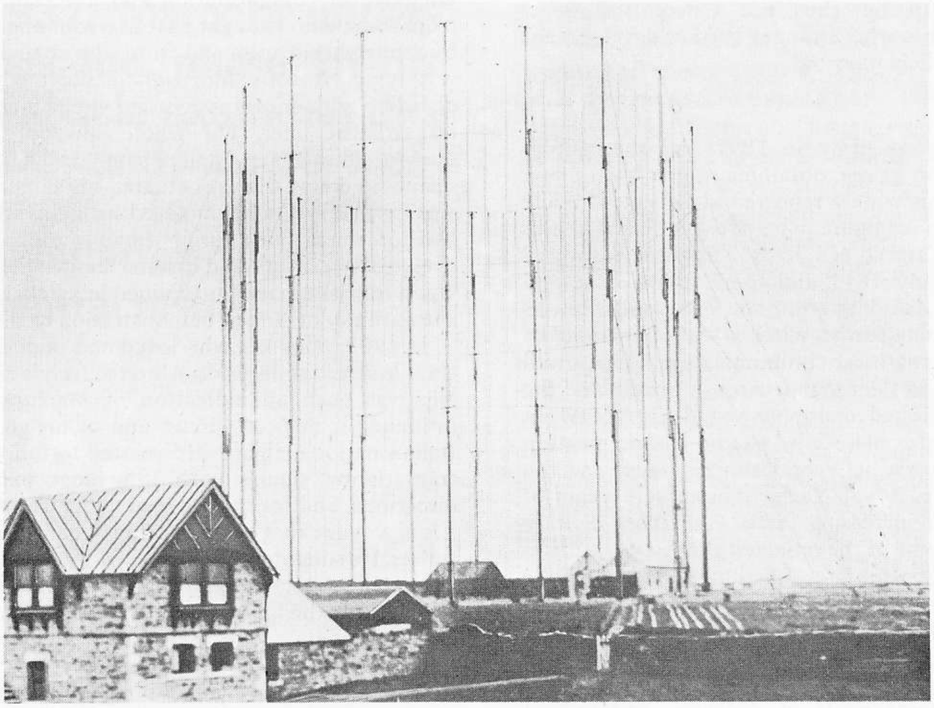
Improved coherer

By the summer of 1895, Marconi's carefully constructed apparatus, which incorporated the modest improvements he had made in the coherer that he was using to detect radiation at the receiver, was capable of ranges greater than the length of his two attics. Accordingly, he took the experiment out of doors and there made the casual discovery which set him on the road to success.

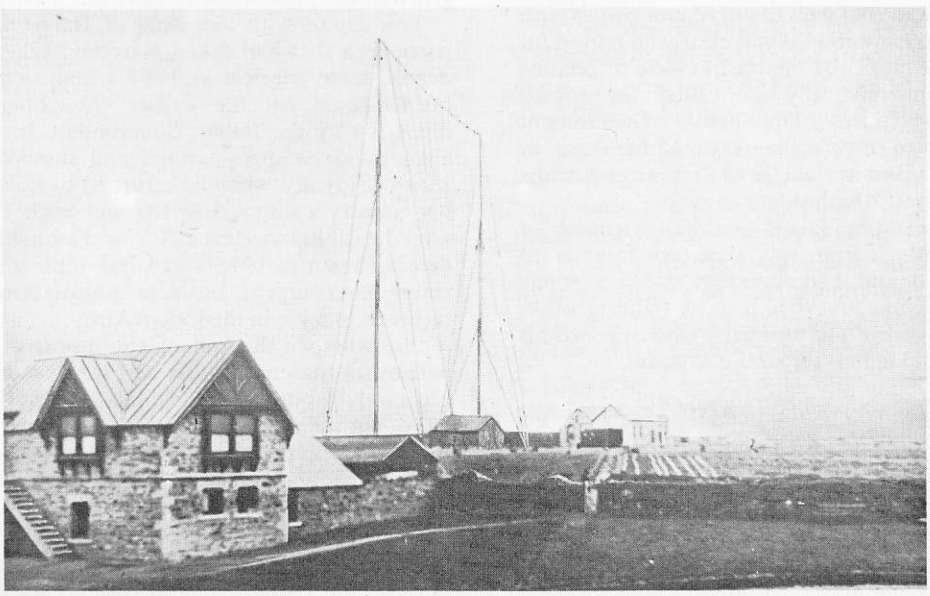
Metal plates had been attached to each side of the transmitting spark gap by experimenters to increase the wavelength, and hopefully the range, of the radiation: corresponding plates were fitted at the receiver. Long afterwards Marconi described what happened,



1 First sketches for a centimetric system prepared by Marconi and Solari while in hospital



2 Original aerial system designed for first transatlantic signals at Poldhu, Cornwall



3 Makeshift aerial which transmitted the letter 'S' after the original aerial had been blown down during a gale

MARCONI CENTENARY

'By chance I held one of the metal slabs at a considerable height above the ground and set the other on the earth. With this arrangement the signals became so strong that they permitted me to increase the sending distance to a kilometre.'

Marconi had little idea then of the significance of the 'aerial' and 'earth' he had discovered, but his progress towards a communication system was now rapid.

In September 1895 he was able to inform the Italian Government through friends in official quarters that he had a pilot radio telegraph system with a range of more than a mile which he was prepared to offer to his country for further development. It was a bitter disappointment when the offer was brusquely turned down without examination or further enquiry.

Once again Marconi's mother took a decisive hand in his affairs. She came to London with him early in 1896, helped him in preparing a submission for a provisional patent, and obtained introductions that led to a demonstration of his equipment to William Preece, Engineer-in-Chief of the General Post Office. Preece was much impressed, and Marconi's wireless was taken up by the Post Office and other Government departments who arranged further development and trials that were publicly reported.

Sea demonstration

He was invited back to Italy in 1897 and successfully demonstrated his system at sea, obtaining signals from a ship below the horizon. This widely reported achievement made him something of a famous figure in his native land and he was taken to meet the King and Queen. Back in England he formed his own company in July 1897 and there followed several years of development, demonstration and increasing fame as Marconi sought customers for his wireless with all manner of displays, particularly in maritime communication. He reported regattas and took part in fleet manoeuvres in Britain and the United States. He established an impressive radio link between England and France, and even installed a radio-communication system for Queen Victoria between Osborne House and the Prince of Wales in the Royal Yacht. These were years of undeniable success and increasing fame. His father in Italy accepted and enjoyed some of the reflected glory.

But success brought enemies, and he had to endure public attacks on his personal integrity from those who accused him of claiming other people's inventions. He was also indirectly attacked through his company by officials seeking more favourable terms for the use of his equipment in Government services, and by business rivals in America, Britain and Germany who had now started well financed companies with good scientific advice to exploit what was clearly an important new world market. The tactics of the clashes were in keeping with what might euphemistically be called the robust commercialism of the times. The British Government commissioned experts to investigate ways of breaking or eluding Marconi patents, and in the United States competitors jammed his company's traffic with vulgar abuse.

The struggle against odds, spiced with an element of personal animosity towards him, was a pattern familiar to Marconi from childhood, and it was one that would continue for much of his manhood. In 1901, he was fighting other members of the board of his own company who opposed his great scheme to send radio signals across the Atlantic.

Hare-brained scheme?

It was in some ways the story of the dark days at Villa Grifone writ large with the Marconi Board, in the role of Giuseppe, needing to be convinced that the plan was not a hare-brained scheme wasting money and effort that would be better deployed elsewhere. Now the money involved was not a few pounds for wire and batteries; it was scores of thousands of pounds for huge radio stations. Now the scientific opposition was not that of academics who were merely uninterested in applying electromagnetic waves to telegraphy; it was the opposition of scientists convinced absolutely that such waves, known to travel in straight lines like light, could not possibly surmount the water piled over a hundred miles high between England and America. But Marconi had already got signals well beyond the horizon and had faith that with a tremendously powerful transmitter and a very sensitive receiver, each served by an enormous, efficient aerial system, it would be possible to get ranges of thousands of miles.

He little knew the difficulties that faced him, nor by what a slender thread of unknown theory his faith would be supported. He secured the co-operation of his board and spent thousands of pounds on equipment—and his careful planning was laid in ruins when the great aerial systems on both sides of the Atlantic were both destroyed by phenomenal weather. But he would not be deterred, or indeed delayed, and it was from a makeshift transmitting aerial in Cornwall that he received the famous 'S' in Newfoundland on a wild December day in 1901 when the wind almost tore away the balloons and kites which he tried in turn to carry aloft the soaring and diving wire that was the pathetic substitute for the great receiving aerial that had been planned.

Congratulation

The furore produced by the news was a mixture of unequivocal congratulation and a certain amount of doubt, from some who thought that Marconi might have been misled by atmospheric noise and from one or two who hinted that he was lying. It took him only a short while to destroy the disbelief with more conclusive experiments performed on a transatlantic liner. The whole episode demonstrated those qualities that Marconi used time and again to bring off the scientific coups that punctuated his career. He was too tough and flexible to be intimidated by opposition to his plans; he had too much faith during the execution of these plans to be deterred by failure and disaster before they came to fruition. When his claims were questioned he rarely argued, he produced a beautifully organised demonstration to silence all doubt.

In 1902, Marconi, who loved and understood the sea, went on a long cruise in Carlo Alberto, Italy's newest warship. The trip was both an indication of Marconi's ability to exert influence in official circles and of his growing stature as an Italian national figure. He wanted to follow up his successful transatlantic signals with long-range experiments in other directions, and for this he needed the use of a ship undertaking a long voyage that was not strictly confined to ordinary trade routes. He sought the assistance of the Italian Government who suggested that he join the Carlo Alberto which came to England for the Coronation Review at Spithead and also took the King of Italy on a State visit to the Czar of Russia. It was felt that the presence of the famous young inventor would add to Italian prestige on these foreign visits, and at the same time give him an opportunity to carry out his experiments.

This cruise with the King of Italy reinforced the natural patriotism that had taken Marconi back to his native land to demonstrate wireless in 1897 when he might so easily have been soured by the earlier thoughtless rejection of his invention by the Italian Government. In 1911, he once more abandoned company affairs and showed his unquestioning national loyalty when he returned to Italy and put himself at his country's disposal in the war with Turkey, in which he served with his wireless at sea, and ashore in the North African desert. Again in 1915 when Italy entered the Great War, he threw over urgent business negotiations in America and returned to serve in the Italian Army.

But whether the call of the moment was of business or patriotism Marconi's great zest for new development in radio was rarely subdued for long. It is perhaps fitting to leave him in 1916, with some of his greatest triumphs still ahead, recovering from illness in a military hospital in Genoa, and experimenting in the corridors with novel very-short-wave equipment, which he had designed and had sent in to him.

This article is based on a lecture delivered to a joint meeting of the IEE Electronics Division and the IERE at Savoy Place on the 25th April 1974 to mark the centenary of the birth of Guglielmo Marconi.

MARCONI

a turning point in radio communication

by G. A. ISTED, C.Eng., M.I.E.E.

From about 1919 until his death in 1937, Marconi undertook the 'second phase' of his work. This article examines this second phase, and, where possible, attempts to suggest a modern explanation to some of his experimental results

Gerald Isted is now retired

This article is based on a lecture delivered to a joint meeting of the IEE Electronics Division and the IERE at Savoy Place on the 25th April 1974 to mark the centenary of the birth of Guglielmo Marconi

When one analyses Marconi's contributions to the art of radio communication, it is quite evident that it was in the field of experimentation associated with radio-wave propagation that he excelled. Marconi was often critical of the attention given to his experiments by both the scientific and popular Press which, he said, reported him 'with varying degrees of accuracy'. His early experiments have been reported and retold by many authors and the main purpose of this article is to give an authentic account of his later experiments which, for one reason or another, have been reported inadequately, sometimes inaccurately and, in some cases, not at all. It is based on original technical papers written by Marconi himself, on authentic records and documents, and on the author's own personal knowledge.

The story begins with a survey paper which Marconi read to the American IEE and IRE in New York in June 1922, the title of which was simply 'Radio telegraphy'. In this paper, Marconi says at one point: 'Some years ago I could not help feeling that we had perhaps got rather into a *rut* by confining practically all our researches and tests to what I may term long waves'. He went on to say: 'The progress made with the long waves was so rapid, so comparatively easy and so spectacular that it distracted practically all attention and research from the short waves'.

At the time, Marconi had, in fact, already set about experimenting with high frequencies in the 3–20 MHz band between Zandvoort in the Netherlands, and Southwold, Hendon and Birmingham in the UK; but he did not share his secret with his American audience.

It would be difficult now to imagine a more complicated and unpromising network of test routes over which to study the behaviour of radio waves. It comprised 'all sea' paths, 'all land' paths and 'mixed land and sea' paths, each with its unique mode of propagation. There were also effects noted which we would now ascribe to the influence of sky waves. A hitherto unpublished report summarised the results obtained. It described, in particular, remarkable differences in the behaviour of signals in the 5–10 MHz band over the different paths and went on to say, 'Whereas at Southwold, about 110 miles from Zandvoort, the night signal is much greater than the day strength, at Birmingham, 282 miles from Zandvoort, the day strength appears normally to be greater than that at Southwold while at night it is impossible to get any sign of the signals'.

There seems little doubt that the day signal at Birmingham was due to propagation by the sky wave. Incredible as it may now seem to us, Marconi actually had the discovery of the 'daylight' wave within his grasp in 1922—but failed to recognise it as such. It was to take him two more years to 'rediscover' it!

Notwithstanding his lack of appreciation of the evidence which had been presented to him, Marconi, within a short space of time, proved the usefulness of high frequencies for long-distance communication to the point that the then existing high-power, low-frequency communication networks became, by comparison, uneconomical and virtually obsolete for point-to-point communication. His long-distance tests, made with the aid of his steam yacht 'Elettra', were first carried out at a frequency of about 3 MHz with which he was soon able to communicate to the furthermost ends of the Earth, albeit only when the great-circle path followed by the radio wave was all, or substantially all, in darkness.

Encouraged by his success in reversing the technological trend towards low frequencies, Marconi began experimenting with still higher frequencies until he reached the point where he could, with the 'rediscovery' of the daylight wave he had missed two years earlier, communicate to anywhere in the world he wished, at almost any time of the day or night, by carefully selecting the appropriate operating frequency. It was at this time, 1924, that the Marconi beam system was

MARCONI CENTENARY

conceived—just 50 years ago!

Marconi in Italy

It was in 1928, soon after the short-wave beam system was universally adopted for long-distance communication, that the Italian Government, recognising that Marconi's reputation and influence would be a most valuable political asset to Italy at that time, set about creating a situation in which permanent residence in Italy would be an attractive proposition to him. So it was that Marconi was nominated President of the Italian Research Council in that year.

In 1929 the hereditary title of Marchese was conferred on him by the King of Italy, and in 1930 he was nominated President of the Italian Royal Academy. If that were not enough, he had recently married one of the most beautiful of Italian ladies. The Italian Government, therefore, gave a very sympathetic ear to Marconi when he expressed a desire to carry out further experiments in radio communication. As a consequence, he was asked to establish a permanent radiotelephone communication link between Sardinia and the Italian mainland, a distance of 270km, in such a manner that it would be resonably secure from interception and interruption by unfriendly powers.

'Weather' and radio-wave propagation

Marconi transferred his staff to Italy and set about designing a pair of stations on the established beam-system principle, with effective radiated powers around 40 kW and, typically contrary to the best advice, he chose a very high operating frequency of around 30 MHz. The stations were built virtually at sea level, one at Golfo Aranci in Sardinia and the other on the site of what is now the Rome Airport at Fiumicino. The link became operational in June 1930, and the results during the succeeding three months were extremely promising.

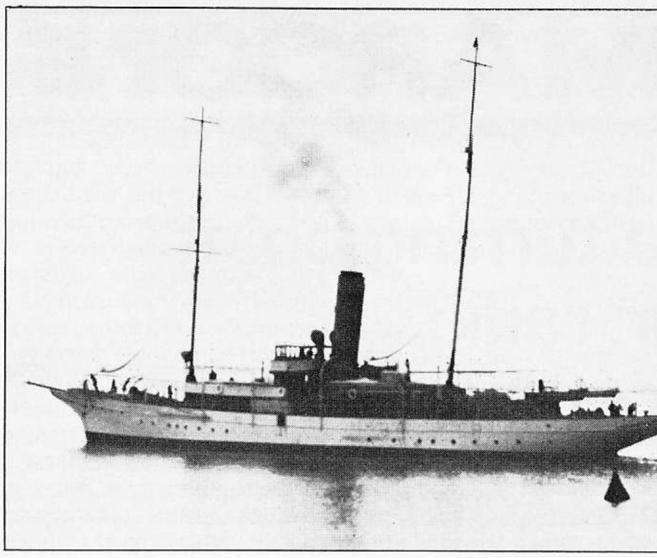
The performance of the link was so reliable that it was decided to hand it over to the Italian Posts & Telegraph to operate. A series of official tests were therefore arranged to commence in the middle of October. Unfortunately, the tests ended in disaster for, within a few days, coinciding with the sudden seasonal change of weather, the mean signal level dropped by more than 20 dB, thereby rendering the link hopelessly unworkable.

Although the Sardinian project ended in commercial disaster, it was not without considerable scientific significance because, probably for the first time, the effect of weather on the propagation of radio waves at the then higher end of the frequency spectrum was established.

The experimental evidence obtained from the Sardinian link prompted Marconi, in his address to the Italian Society for the Progress of Science in 1930, to say; 'From measurements effected recently it would seem that along the route between Sardinia and the Italian mainland this wave is refracted and contained within a space lying between the surface of the Earth and a layer situated somewhat lower than the Heaviside layer'. What a good description of the troposphere as we know it today—considering that it was made over 40 years ago!

Marconi and microwave communication

Was Marconi discouraged by the failure of his latest experiment? Quite clearly he was not! In a paper he read before the Royal Institution in London in 1932 he said: 'The remarkable results which I obtained during the period of 1919–1924 with the use of wavelengths from 100 to 6 m again distracted my attention from the study of microwaves'. The paper then went on to describe his first experiments at



1 *(above)* SY *Elettra* leaving harbour for one of her tests

2 *(above right)* Inauguration of the first microwave telephone service between the Vatican and Castel Grandolfo, the Pope's summer residence. Shown in the picture (from the right): Pope Pius XI, Cardinal Pacelli (who became Pope Pius XII). On the left are Marconi, G. A. Mathieu (with headphone on) and in the background G. A. Isted, both assistants of Marconi

3 *(right)* Early type of 600 MHx electron oscillator using one pair of push-pull valves. The dipole is capactively loaded by circular end discs. Tuning is by means of Lecher wires

frequencies as high as 600 MHz; how first he had to develop practically every piece of apparatus from scratch.

It was with equipment crude and simple by modern standards that Marconi set out in 1931 supremely confident that he would, yet again, confound the false prophets of the day who were of the opinion that propagation of microwaves beyond the horizon was an impossibility.

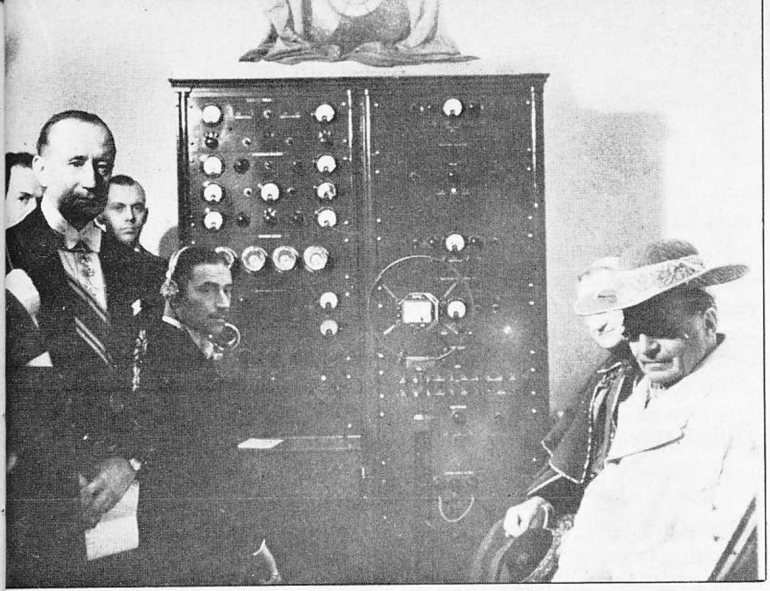
The first tests on frequencies of 600 MHz were made between a villa overlooking Genoa harbour and a motor boat from the *SY Elettra*. Although signals were received well out to sea, they were not what one might call robust; neither were the transmitting and receiving valves, because their lives, at that time, were still only three or four hours at the best. But it was a beginning.

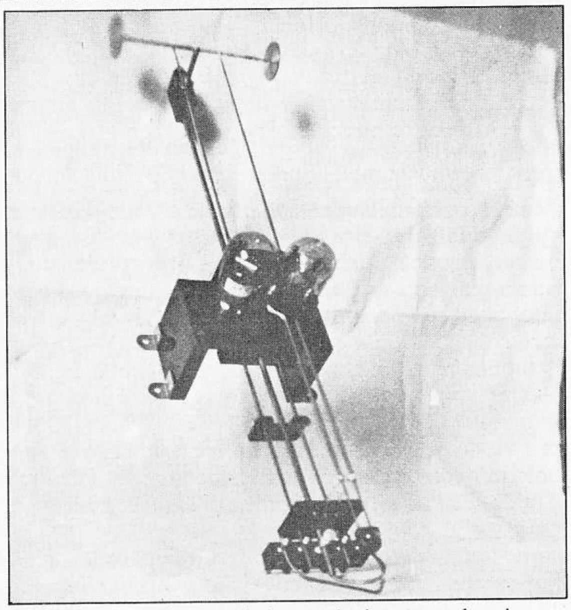
Tests continued during the summer from a transmitter installed on the balcony of a villa situated in the foothills at Santa Margherita overlooking the Ligurian Sea.

Interest at the Vatican

By the Autumn, it was possible to transmit good speech between Santa Margherita and a disused signal tower at Sestri Levante, a distance of 19 km, and between Santa Margherita and Levante, a distance of 29 km. Many demonstrations were given in quick succession to the Italian Ministry of Communication and representatives of the Press.

Improvements in equipment and techniques were continuously being made and, by April 1932, it was possible to demonstrate a complete duplex telephone system capable of being extended to 2-wire subscribers. Soon after this, the Vatican authorities expressed an interest in the possibility of linking the Vatican City with the summer residence of His Holiness the Pope at Castel Gandolfo, a land path of 24 km obstructed at two points by dense trees.





MARCONI CENTENARY

Not having the experimental data relating tree density to signal attenuation, Marconi decided to carry out a radio survey to determine the possibility of communicating over such a path. The tests, in fact, indicated that trees did not, on that route, constitute a serious obstacle to microwaves.

The subscriber-to-subscriber telephone and teleprinter link was completed by the end of the year and subsequently officially inaugurated by His Holiness the Pope in February 1933, and thus became the first microwave telephone subscriber link ever to go into service. It was over this link that the Pope's words were relayed to the main short-wave transmitter at the Vatican when he consecrated the new cathedral at Messina.

Marconi's study of microwave propagation

Marconi was satisfied that he had sufficiently demonstrated the usefulness of microwaves for relatively short communication links, and he was content to leave it to his commercial organisation to develop the idea. His ambition was clearly to break down the barriers that appeared to him to be imposing an unreasonable limitation to the propagation of microwaves to substantial distances. With this in mind, and disregarding the opinions of the great men of science who 'knew' that microwaves could not be transmitted beyond the horizon, he set about studying in more detail the laws governing their transmission characteristics to greater and greater distances.

In July 1932, the first investigations of reception at relatively long distances were carried out on the yacht *Elettra* from a more powerful transmitter which had been installed on the terrace of the Hotel Miramare at Santa Margherita, at a height of 13–15m above sea level. These tests indicated immediately that signals could be received well beyond the optical range.

Sardinia again

Marconi then made one of his snap decisions. He would try to bridge the route between Sardinia and the Italian mainland by microwaves—this despite his lack of success in his previous attempt to do so on a frequency of 30 MHz.

The transmitter was thereupon dismantled and transported to the obsolete seismographic observatory, situated at a height of 650m, at Rocca di Papa, about 19 km south of Rome and overlooking Fiumicino. The receiver was, as usual, installed on the upper deck of the *Elettra*.

Following a very brief test over a distance of 29 km, Marconi confidently invited representatives of the Italian Government on board the yacht to accompany him on the cruise to Sardinia and witness the tests he was about to make. All was ready on the 6th August 1932, and the yacht took up a position on a line joining Fiumicino and Golfo Aranci, Sardinia—an almost identical route to that of his earlier 30 MHz tests.

Signals were received continuously up to a distance of 190 km at which point they became inaudible.

On reaching Golfo Aranci, the receiving apparatus was disembarked and transported to the signal station at the top of Cape Figari at a height of 300m above sea level. Strong signals, giving for much of the time 100% intelligible speech, were received for several hours, although, at times, there was severe fading.

The distance between the terminals was 270 km—quite an achievement considering the relatively crude apparatus available at that time! Nevertheless, while the tests had been successful and Marconi had shown that a microwave communication link would function between Sardinia and the mainland, the Italian Government representatives were sceptical about its long-term reliability and expressed the hope that Marconi would carry out extended tests, over considerable distances, to obtain reliable propagation data before they could consider incurring expenditure on a commercial installation. Marconi was quite happy to fall in with their wishes; he had proved his point and a good time had been had by all on board and beyond that he had several other lines of research which had been occupying his mind for some time.

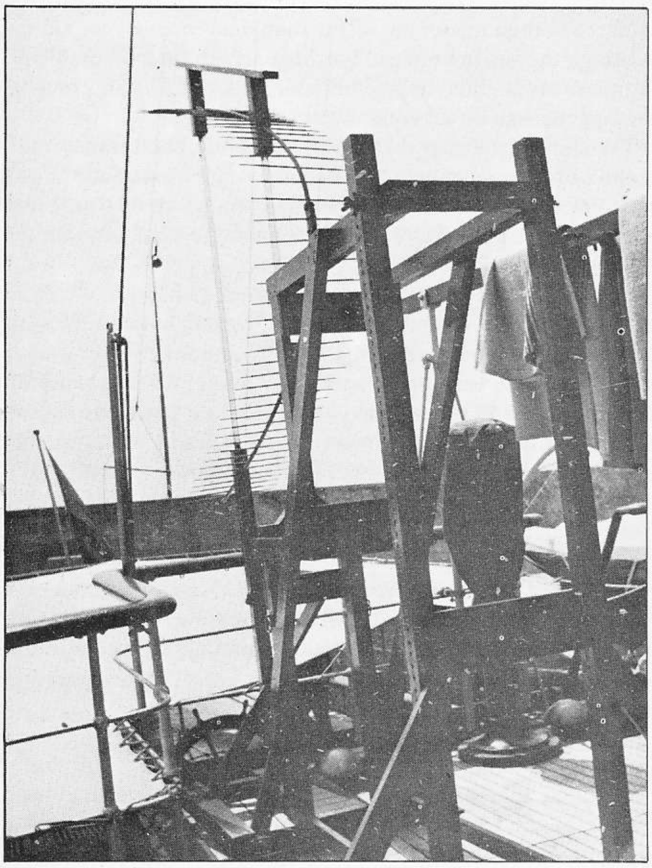
First steps towards 'radar'

High on Marconi's list for further investigation was a phenomenon he had noticed during the testing of the Vatican microwave installation. The transmitting and receiving dipoles in his installation were situated side by side in the same 4-unit fish-bone parabolic reflector. The system would normally have been controlled by a 'voice-operated device', but, on this occasion, for some reason, it was being dispensed with so that the tone modulation used for adjusting system levels, which was then being transmitted, was received on the adjacent receiving dipole. This condition was often used when it was desired to monitor the outgoing signal.

From time to time, on this particular occasion, a strange rhythmic undulation of the monitored signal was noted. This was at first attributed to malfunctioning of the equipment, but a thorough check failed to reveal a plausible explanation and some time elapsed before Marconi realised that the rhythmic variation of the monitored signal seemed to occur each time a steamroller, making up the road in front of the aerials, moved.

Immediately Marconi knew he was in fact detecting a moving object in exactly the manner that he himself had specified in his paper to the American IEE and IRE in New York ten years earlier. Had he made the first 'radar' observation?

MARCONI CENTENARY



4 The fishbone parabolic reflector installed on board the *SY Elettra* for the Rocca de Papa—Sardinia microwave tests

Further controlled tests were carried out and it was found that a man walking in front of the aerials could also be detected. Over the ensuing year, when more experience had been obtained in controlling the crude radar device, motorcars could be detected about 2·5 km away.

The climax to this particular investigation came on the 14th May 1935, when a demonstration was given to Mussolini, then Head of the Italian Government, who foresaw an application in connection with his military adventures in Abyssinia which erupted a few months later.

'Blind' navigation by microwaves

Throughout his career, Marconi was always seeking ways and means of ensuring the safety of ships at sea. This urge was particularly keen while he was investigating the possibilities of utilising microwaves, and it was in the field of marine navigation by microwaves that he gave one of his most spectacular demonstrations.

He had conceived the idea of guiding a ship through a narrow entrance to a harbour in conditions of zero visibility. To demonstrate this Marconi arranged to have mounted at right angles to one another two broad-beam reflectors with their respective horizontal dipoles fed 180° out of phase from a common transmitter. In this way a very sharp zone of minimum signal was created in the centre of an otherwise broad region of high signal level. The whole aerial head was then made to oscillate to and fro by about ± 15°, so that the sharp minimum scanned a sector of 30°.

The transmitter was modulated by two tones alternately, the change over from one tone to the other taking place when the aerial minimum was directed exactly along the desired navigation course.

On board the *Elettra*, the same type of four-valve receiver, which had been used so successfully in all previous experiments, was modified to incorporate two note filters, corresponding to the two modulation tones applied to the transmitter; their respective detectors, giving d.c. outputs, were then fed into a centre-zero indicating instrument. By this arrangement, the needle of the indicator was deflected left or right (port or starboard) according to the tone that was being received at that moment.

When the 'beacon' head was scanning correctly left and right about the desired approach course, the indicating instrument would be deflected equally, also left and right, provided that the ship was correctly positioned on the approach course. Should the ship deviate from the predetermined course, an unequal deflection to left and right would be noted on the indicator. All that was necessary to keep the ship on the desired approach course was to ensure, by altering course if necessary, that equideflection was maintained on the indicator.

Tests commenced early in 1934 and proved to be so successful that Marconi, in a very confident mood, planned an elaborate demonstration and invited on board the *Elettra* representatives from all the big British shipping lines and from Trinity House.

For the demonstration the navigational beacon was installed on the promontory at Sestri Levante at a height of 90m above sea level. Two buoys were then anchored 90m apart at a distance of 800m from the shore to simulate a harbour entrance.

On the 30th July, the *Elettra* steamed out to sea from her anchorage at Santa Margherita with Marconi's guests on board. With all the blinds of the chart room drawn, so that it was impossible for the navigator to see, the yacht was successfully steered through the two buoys solely by means of the indication given by the beacon. The manoeuvre required little skill and many of Marconi's guests took turns to do it themselves.

The success of the demonstration caused a flurry of excitement amongst the guests—but more was yet to follow!

MARCONI CENTENARY

Marconi had also arranged for two similar buoys to be anchored at the entrance to the harbour at Santa Margherita. By turning the receiver to face astern, and by reversing the connections to the indicator, Marconi then proceeded to carry out the same manoeuvre, again most successfully, but this time at a distance of 16 km from the beacon! This, one must remember, happened 40 years ago. Could we do much better now?

'Obstacle gain'?

In parallel with the radio beacon and other experiments, a great effort had been made to develop a more powerful and reliable transmitter with which to study the behaviour of microwave propagation over an extended period of time and at relatively long distances.

The first experiments were made in August 1933 with improved transmitting and receiving equipment. The transmitter was installed on the terrace of the Hotel Miramare at Santa Margherita and, for the first time, a parabolic dish of 1·5m aperture was used. A similar dish was used for the receiver and this was mounted at the stern of the *Elettra* at a height of about 5m above sea level. The combined heights of the transmitter and receiver provided an optical range of about 30 km.

Among the many successful cruises that were carried out between the 2nd and 6th August, there is one of outstanding interest. The *Elettra* sailed southwards from her anchorage at Santa Margherita on a course that would take her between the island of Elba and the Italian mainland. Signals were received continuously, and at great strength, up to a distance of about 160 km, about five times the optical range. Beyond this distance the requirements of navigation did not allow the receiving dish always to be correctly directed towards the transmitter; the signal, in consequence, was not observed for long periods. Nevertheless, when the *Elettra* finally reached her anchorage at Porto Santo Stefano, a distance of 260 km from the transmitter, signals were again received but at a somewhat reduced strength; this was at more than eight times the optical distance.

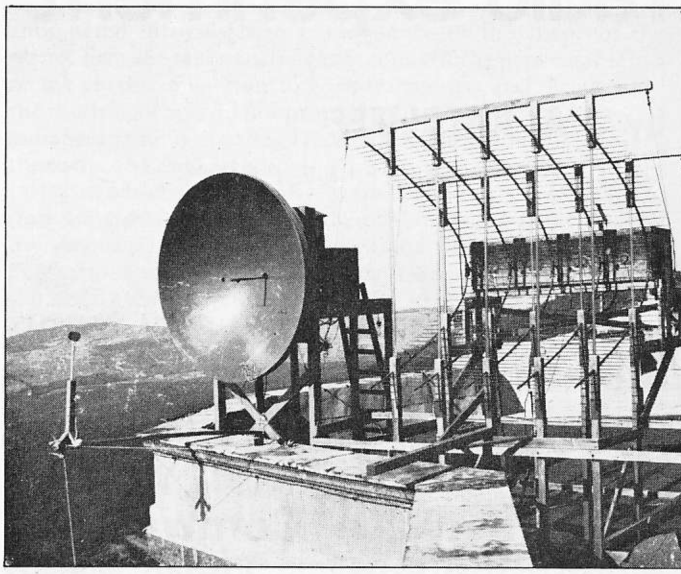
The real point of interest of this test, apart from the remarkable distance over which signals were received, lies in the fact that the route between Santa Margherita and Porto Santa Stefano was badly obstructed by the promontory of Piombino rising to a height of 300m above sea level. The propagation mechanism by which the signals were received on the *Elettra* must be a matter for conjecture. Could it have been a classic example of diffraction over a knife-edge giving so-called obstacle gain?

Marconi the man

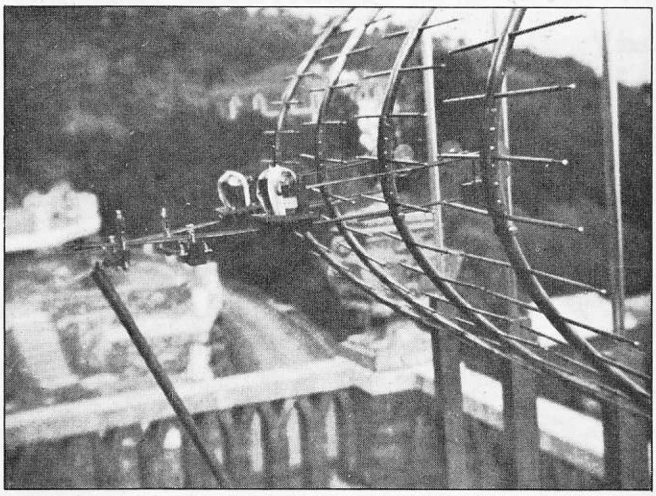
What kind of person was this man Marconi, the man we all called 'G.M.'? While it cannot be said that Marconi 'invented' wireless, it certainly can be said, with little fear of contradiction, that he had a remarkable gift of invention and experimentation. He had, in fact, what one might term 'wireless greenfingers'.

A remarkable characteristic of Marconi was his ability to think big and to persuade others to think big with him. Most of his outstanding experiments were carried out in a most grandiose manner and probably on a scale that would not be considered economically prudent today; but such was his fanatical obsession with wireless that he brushed aside such mundane considerations as cost effectiveness. Marconi never allowed reports of his work to be made public until he was certain of his conclusions.

Marconi was a good chief to work for, provided that you quickly came to terms with the idea that you were expected to be on duty 24 h a day, seven days a week. He drove his assistants hard, but never so hard as he drove himself, and he never asked his assistants to do something that he was unable or unwilling to do himself.



5 Two types of parabolic reflector used at Rocca de Papa for communication with the *Elettra* on the microwave test terminating at Golfo Aranci, Sardinia



6 Early 600 MHz transmitters and receivers were mounted crudely at the back of fishbone parabolic reflectors

MARCONI

reactions to his transatlantic radio experiment

by J. A. RATCLIFFE

C.B., C.B.E., M.A., C.Eng., F.I.E.E., F.R.S.

Did Marconi receive any transatlantic signal in 1901? If he did, how did the signal surmount the 160 km wall of water between Cornwall and Newfoundland? These two questions occupied the engineers and scientists of the day, and many were concerned with the commercial applications that the experiments heralded

John Ratcliffe, now retired, is a past-president of the IEE

This article is based on a lecture delivered to a joint meeting of the IEE Electronics Division and the IERE at Savoy Place on the 25th April 1974 to mark the centenary of the birth of Guglielmo Marconi

During daylight in December 1901, Marconi received radio signals that had travelled to America from a sender at Poldhu in Cornwall, a distance of 3500 km. In their travel, the waves had surmounted a wall of ocean 160 km high. A little later in January 1902, he crossed the Atlantic in a ship, the *Philadelphia*, and received signals from the same sender up to a distance of 1120 km by day and 2500 km by night. Previously, radio signals had been received over distances of only a few hundred kilometres, and over hills that were only a few hundred metres high. The new results were surprising in the extreme and it is interesting to examine how they were received by scientists and technologists. I shall discuss first the reactions of Marconi's contemporaries, and secondly the reactions of the present day.

The views of Marconi's contemporaries

At the time of the experiment, scientists and technologists took little notice. The views of the Institution of Electrical Engineers (which had previously been called the Society of Telegraph Engineers) were summarised in 1902 by their President who said, 'We can get but few telegraph papers now, this is not because telegraphy is dead, it is because most of its problems are solved, so there is little to discuss. (Telegraphy) has passed out of the childhood of technical difficulties and into the manhood of commercial development'.

The *Electrician*, the leading technological journal at the time, noticed Marconi's achievement in a series of editorials, all of which were aimed at explaining that 'wireless' was in no way competitive with cable telegraphy. Nowhere was there any editorial comment on the important scientific problems posed by Marconi.

We must recognise that both the technical Press, and even the professional Institution, were chiefly interested in the possible commercial repercussions of the experiment. Their reactions were surely unbecoming to professional engineers. I hope it would not be possible nowadays that there could be similar reactions in a similar situation; our Institution should be on its guard.

Meanwhile what did the mathematicians and scientists think about the experiments? In 1903, Macdonald made a theoretical investigation of 'the bending of electric waves round a conducting obstacle', and concluded that radio waves would travel from England to America with very little attenuation. But Rayleigh immediately countered by saying 'Macdonald's results . . . appear to me to be open to objection. The first objection that I have to offer is that nothing of this sort is observed in the case of light. The relation of wavelength to diameter of object is about the same in Marconi's phenomenon as when visible light impinges on a sphere one inch in diameter. So far as I am aware no creeping of light into the dark hemisphere through any sensible angle is observed under these conditions even though the sphere is highly polished.' He then proceeds: 'But I shall doubtless be asked whether I have any complaints against the mathematical arguments', and explains in detail why the mathematics was wrong. The interesting point here is that even a mathematician with the ability of Rayleigh preferred to view the problem in the light of physical common sense rather than through an elaborate piece of mathematics. We should all do well to follow Rayleigh's example.

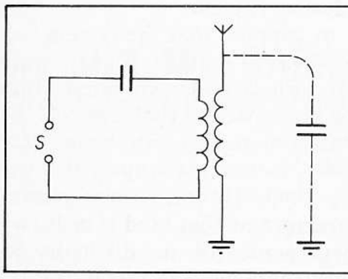
But, in spite of Rayleigh's comments, it was generally accepted (on quite inadequate grounds) that an earthed aerial would radiate some kind of surface wave that was guided by the conducting seawater so as to arrive in America only slightly attenuated.

Heaviside had shown theoretically how waves could travel along wires and how they would follow a wire round a corner, and in 1902 he suggested that they could equally be guided round the earth by the conducting ocean. He added, almost as an aside, 'There is another consideration, there may possibly be a sufficiently conducting layer in the upper air. If so, the waves will so to speak, catch on to it more or less, then the guidance would be by the sea on the one side and by the upper air on the other.' That almost parenthetical remark was the first suggestion of the Heaviside layer.

Meanwhile Kennelly had made a much more detailed suggestion. He considered that air would conduct simply because it was at a low pressure, and he concluded that the conductivity at a height of 80 km would be greater than that of seawater. The waves will then travel between the reflecting surface of the ocean beneath, and a reflecting surface in the rarefied air above, so that the curvature of the Earth will be unimportant.

These two suggestions immediately lead us to ask two questions: 'Why do we now call the conducting layer after Heaviside and not after Kennelly?' and 'Why did Kennelly think that air will conduct simply because it is at low pressure (for it must be noted that he made no reference to any ionising agency)?'.

The answer to the first question has been given by Eccles, who wrote, in 1927, 'May I explain why I happened to choose the name "Heaviside layer" some sixteen years ago? In the Spring of 1902 I was writing from time to time on wireless telegraphy in the pages of the *Electrician*, and one day Mr. Tremlett Carter, the editor, showed me a letter from Mr. Oliver Heaviside which, while discussing other things, asked if the recent success of Mr. Marconi in telegraphing from Cornwall to Newfoundland might not be due to the presence of a permanently conducting upper layer in the atmosphere. I believe this letter was shown to various friends of the editor, but I think it was not published. In about 1910 I used the convenient name "Heaviside layer" in a paper, to indicate the portion of the atmosphere that functions so usefully for the purpose of wireless telegraphy.'.



1 Simplified version of the circuits at the transmitter

The second question is answered when we notice that Kennelly was following the view expressed by J. J. Thomson in 1896, before he and Rutherford had realised the need for an ionising agency. 'J. J.' had measured the conductivity of air in an ingenious experiment where the eddy currents in a tube containing air at low pressure had been used to shield the secondary of a high-frequency transformer from the effects of a nearby primary. In his book he quoted the conductivity of air at a pressure of 0·01 mm of mercury, and it is this conductivity that Kennelly used.

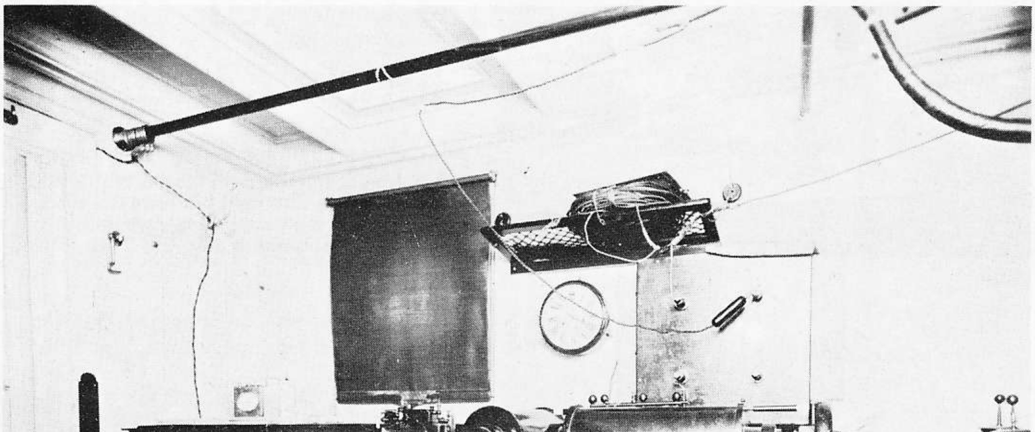
MARCONI CENTENARY

But in spite of the suggestion of the 'Kennelly–Heaviside' layer, the common view was that expressed by Marconi himself in 1909 when he said: 'With regard to the presumed obstacle of the curvature of the Earth, I am of opinion that those who anticipated difficulties in consequence of the shape of our planet had not taken sufficient account of the particular effect of the earth connection to both transmitter and receiver . . . the resulting waves do not propagate in the same manner as free radiation from a classical Hertzian oscillator, but glide along the surface of the Earth.'

Those who believed in this 'guided-wave' theory then had to find some way of explaining the different ranges of the signal by day and by night, as observed in the *Philadelphia*. Suggestions were made that 'daylight dissipated the charge on the aerial'; that the 'ether drift', being in opposite directions by day and by night, would hinder the wave more by day; and, more reasonably, that ionisation of the atmosphere near the ground, by electron streams or light from the sun, would absorb the waves. It was not until 1912, when Eccles presented a detailed discussion of the 'layer' theory of Kennelly and Heaviside, that absorption of the waves in the upper atmosphere was considered.

Did Marconi really hear the signals?

Because the arrangements for receiving the signals in America were very simple, it has often been suggested that Marconi deceived himself in believing that he had heard the test transmissions from Poldhu. The aerial was a long wire supported by a kite which moved in the wind, the observations were made by listening in telephones and consisted of hearing the three dots of the Morse letter S, at times when they were expected, against a background of atmospherics: it is easy to



2 Marconi's equipment fitted in the cabin of the Philadelphia

MARCONI CENTENARY

doubt the reality of the result under these difficult conditions. Now that we know in some detail the effect of the ionosphere (the Kennelly-Heaviside layer) on radio waves, it is thus interesting to make detailed calculations and to see whether we might or might not have expected Marconi's experiment to be successful. We must decide what power was radiated and on what frequency, what field strength was produced at the receiver, and whether this was great enough to produce a response in the telephones.

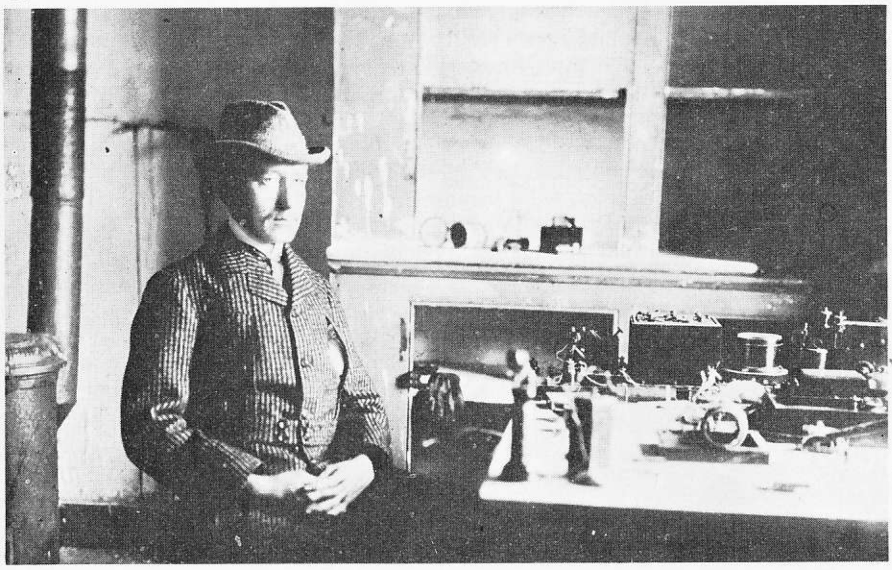
The essential circuits of the transmitter were as shown in Fig. 1. The waveform of the radiation that is emitted each time the spark gap S breaks down can be calculated from the published description of the circuits, and the average power in this transient radiation can be estimated. It is found that the spectrum of the radiation has important components at all frequencies between about 0·5 and 9 or 10 MHz, and near the lower frequency there is a comparatively sharp spectral line. This particular form of spectrum arises because the two oscillatory circuits were very closely coupled. From our knowledge of wave propagation we can estimate the power that would arrive in America by day, or on the *Philadelphia* by day or by night, over different parts of the spectrum, and we conclude that only that part with frequencies greater than about 5 MHz or near the spectral 'line' at 0·5 MHz would be appreciable.

The next step is to decide whether the power available in either of these two frequency ranges would be sufficient to operate the receiver. Fortunately, the Science Museum has a detector of the type used in America, and its characteristic has been measured by Dr. Grisdale of the Marconi Co. In America it was used in series with a long wire supported by a kite and G. R. M. Garratt, formerly of the Science Museum, has suggested that this untuned arrangement responded to that part of the broadband spectrum with frequencies greater than about 5 MHz. The calculations show that, if all circuits were ideally efficient, this power would suffice.

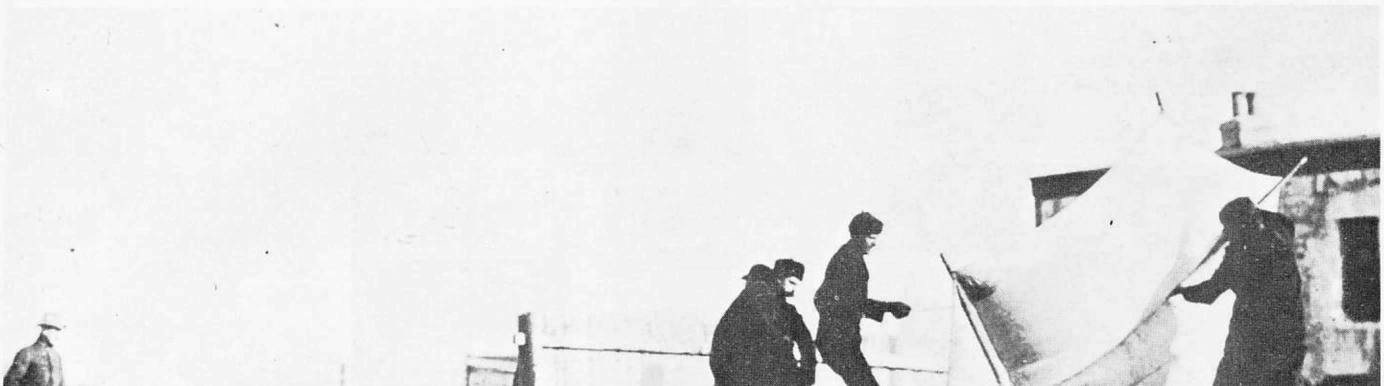
On the *Philadelphia*, however, the receiver was comparatively sharply tuned, and it seems more probable that reception was on a frequency near 0·5 MHz where there was a fairly sharp spectral line. Again, to explain the reception, we must suppose that all circuits were ideally efficient.

It is, of course, unrealistic to suppose that the system was ideally efficient. If, then, we believe that the signals were received, we must suppose that we have underestimated either the power of the sender or the sensitivity of the detector. We know for certain that the signals were received on the ship, for they were recorded automatically, so we must suppose that the power or the sensitivity was perhaps 10 or 20 times greater than our estimate. When a correction of that kind is made we must also conclude that there would be no difficulty in receiving the signal in America. Any suggestion that it was too weak to be received must imply also that the signal on the *Philadelphia* was too weak. It appears that Mr. Garratt's ingenious idea is probably correct, and that there is no support for the suggestion that Marconi deluded himself.

In the writing of this article I have had valuable help from E. N. Bramley, K. G. Budden, G. R. M. Garratt, G. L. Grisdale and M. Smith



3 Marconi at Signal Hill, Newfoundland, in 1901 with the instruments with which he received the first wireless signal across the Atlantic from Poldhu, Cornwall



4 Raising the kite aerial at Signal Hill. Hydrogen balloons were also tried but were less successful than kites in the strong squally winds. Marconi is seen at the extreme left

MARCONI

the Lavernock trials, May 1897

by G.R.M. GARRATT
M.A., C.Eng., F.R.Ae.S., F.I.E.E.

'The results of these tests in the Bristol Channel gave conclusive proof of the inherent possibilities of the system '

J. GAVEY., E–in–C., GPO Nov. 1902.

The experiments that were carried out by Marconi on Salisbury Plain in September 1896 and March 1897 served to demonstrate that his system of signalling by the use of Hertzian waves had some potential value, but the results, although extremely interesting, were somewhat tentative. They had served, however, to arouse serious interest in the Post Office, and it was therefore decided to institute a series of official trials with the specific object of ascertaining the practical value of Marconi's methods. The results of the trials were of immense importance, but the details have not been published previously.

The trials were held in May 1897 between Lavernock Point, about five miles south of Cardiff, and the island of Flat Holme in the Bristol Channel, a distance of about 3·3 miles. This location was chosen, partly because it provided a convenient site for testing transmission over water, but mainly because it had been the site where tests had been carried out several years previously of Preece's 'parallel-wire system' for signalling across stretches of water, by means of conduction, in circumstances where the laying of a cable was not practicable, e.g. between the shore and a lighthouse. It now provided a reliable means of communication between Lavernock Point and Flat Holme island while tests with the somewhat fickle Marconi apparatus were in progress.

Goodwill

It is perhaps desirable to bear in mind that the Lavernock trials were in every sense official Post Office trials, carried out principally by Post Office staff, though with the close co-operation and goodwill of Signor Marconi who, at the time, was only just twenty-three years of age.

Prior to the commencement of the tests, a pair of masts about 110 ft (35 m) high had been erected at Lavernock Point and on Flat Holme. At that time it was believed that a substantial area of capacity was a desirable if not an essential feature of a wireless aerial and large drums of sheet zinc, suitably supported and insulated, were therefore installed at the top of each mast. According to Fahie[1], these 'elevated capacities' were cylindrical caps, 6 ft (1·8 m) long and 3 ft (0·9 m) in diameter and they were connected to the signalling apparatus at the foot of each mast by substantial strands of gutta-percha covered aluminium wire. A number of thick stranded copper wires leading over the edges of the cliffs into the sea made the earth connections.

The apparatus used throughout the Lavernock trials was partly Marconi's own equipment and partly modified and redesigned gear made up in the Post Office workshops, but, as was perhaps inevitable at that early stage, much of the equipment was of a crude nature that left much to be desired before it could be developed into a reliable system for practical use.

Unsuitable oscillator

The transmitter on Flat Holme employed a Rhumkorff induction coil connected to a Righi oscillator, a device which was peculiarly unsuitable for use at the frequencies Marconi was now using. Briefly, the Righi oscillator comprises of a set of four brass spheres, the two central ones being about 4 in (10 cm) in diameter and seperated by a gap of approximately 1–1·5 mm, while the two outer spheres were each about 1 in (2·54 cm) in diameter and separated from the respective inner balls by a gap of about 0·5 in (1·27 cm). The secondary winding of the induction coil was connected to the two outer spheres, so that the spark discharge had to bridge the three gaps in the aerial-earth system. Three different coils were used during the experiments. The first, a powerful instrument capable of giving a 20 in (50·8 cm) spark, had been specially purchased by the

Gerald Garratt was formerly with the Science Museum, South Kensington, London SW7. He has now retired

MARCONI CENTENARY

Post Office. The second was a small instrument of similar pattern giving a 6 in (15·2 cm) spark. The third, the property of Signor Marconi, was of intermediate size, but it became defective early in the tests and the main work was carried on with the Post Office coils.

From the several sources that are available to us, it is possible to piece together a fairly complete list of those who attended the trials during at least part of their duration. Among the Post Office officials there were Mr. (later Sir) William Preece, the Engineer-in-Chief, John Gavey, a Principal Technical Officer and Preece's successor, Mathew Cooper and J. E. Taylor. The War Office was represented by Major C. Penrose and the Royal Engineers by Major G. A. Carr and Captain J. N. C. Kennedy. Prof. Viriamu Jones of University College, Cardiff, was an 'interested spectator'. The one whose presence was to cause more trouble than any other for the future Marconi Company was Prof. A. Slaby of Charlottenberg, who had been reluctantly invited by the Post Office at the personal request of the German Emperor.

Pocket diary

A name that, surprisingly, does not appear in any of the contemporary accounts is that of G. S. Kemp, the man to whom, more than any other, we are indebted for the day-to-day account of the Lavernock trials. Kemp had joined the Royal Navy at the age of 15, and when he was discharged in 1895 at the age of 38, he joined the staff of the Post Office as an assistant in the Engineer-in-Chief's Laboratory. In that capacity, he had been instructed to assist Marconi in the earlier experiments on Salisbury Plain. With the decision to hold the more extensive trials in the Bristol Channel, Kemp was made responsible for transporting and setting up the apparatus at Lavernock and Flat Holme. Following his life-long habit, Kemp recorded brief details of his daily activities in a pocket diary; it is to this diary—and particularly to the expanded and edited versions that Kemp prepared for the Marconi Company in about 1930—that we are indebted for the details which follow.

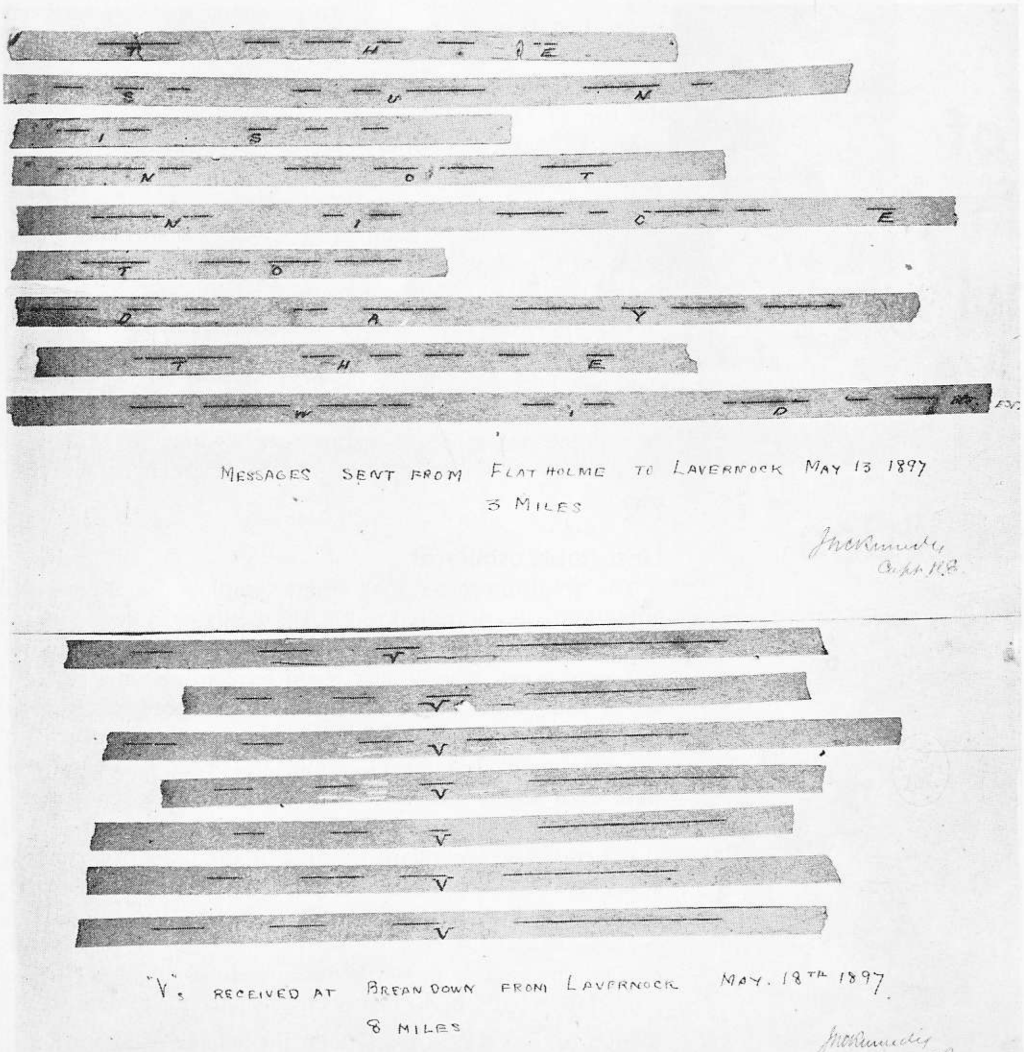
In Kemp's words, the historic experiments started early:

Thursday 6th May

'Left at 8.30 a.m. for Paddington with apparatus for experiments at Cardiff. Arrived at 2.17 p.m. and stowed apparatus in store. Proceeded to Lavernock to see mast and found that a long cable had been fixed, stretching out beyond low-water mark, for the earth connection. Fixed a wire atop the 107 ft pole, 16 strands of aluminium wire. Then returned to Cardiff and made arrangements for transporting apparatus to Flat Holme Island.'

Friday 7th May

'I packed Mr. Marconi's transmitter into a small tug at 6.30 a.m. together with the transmitting and receiving apparatus belonging to Mr. Preece's Parallel Wire system and transported all to Flat Holme Island. Fixed a wire of 18 strands to top of 110 ft pole and prepared Mr. Marconi's transmitter in a small hut close to mast. Slept at a small house owned by the person in charge of the Cremation House.'



Signals on tape received at Lavernock from Flat Holme and at Brean Down from Lavernock during May 1897. The witnessing signature is that of Capt. J. N. C. Kennedy who attended the trials on behalf of the War Office (Marconi negative 5913)

MARCONI CENTENARY

For the next few days, Kemp was busy on the little island, fitting up and testing Marconi's transmitter and Preece's parellel-wire system. He had trouble with the insulation of the zinc drum at the top of the mast and with the insulation of the stays. Sparks on the parallel-wire system also caused difficulties whenever he used the Marconi transmitter, but these were only 'teething troubles' and by the Wednesday of the following week he was able to record that 'The signals transmitted across to Lavernock by Mr. Marconi's transmitter and the Parallel Wire system were good'. Insulation, however, was still proving troublesome and his next comment was 'As I did not like the insulation of the drum, I sent some of these signals on the aerial which was connected to insulated stays', which is a reminder of the very high voltages encountered in the aerial circuits of the early spark transmitters.

A brief mention was made above of the two versions of Kemp's diary, the original contemporary pocket diary[2] (parts of which the owner, his son, Leslie Kemp, kindly permitted me to photograph some years ago) and the expanded version* which Kemp prepared for the Marconi Company in about 1930. The latter version contains an amount of detail to which no reference is made in the original, and while no actual contradictions have been noted, it is difficult to avoid wondering how an old man (he was more than 70 at the time) writing more than thirty years after the events could have remembered many of the trivial details he mentions. In the original diary, the events of the time from Monday the 10th to Friday the 14th May are bracketed together with the single comment 'Signalling with Marconi and Parallel Wire systems to Lavernock Point' but, in the 1930 version, the daily events are recorded with considerable detail, e.g.

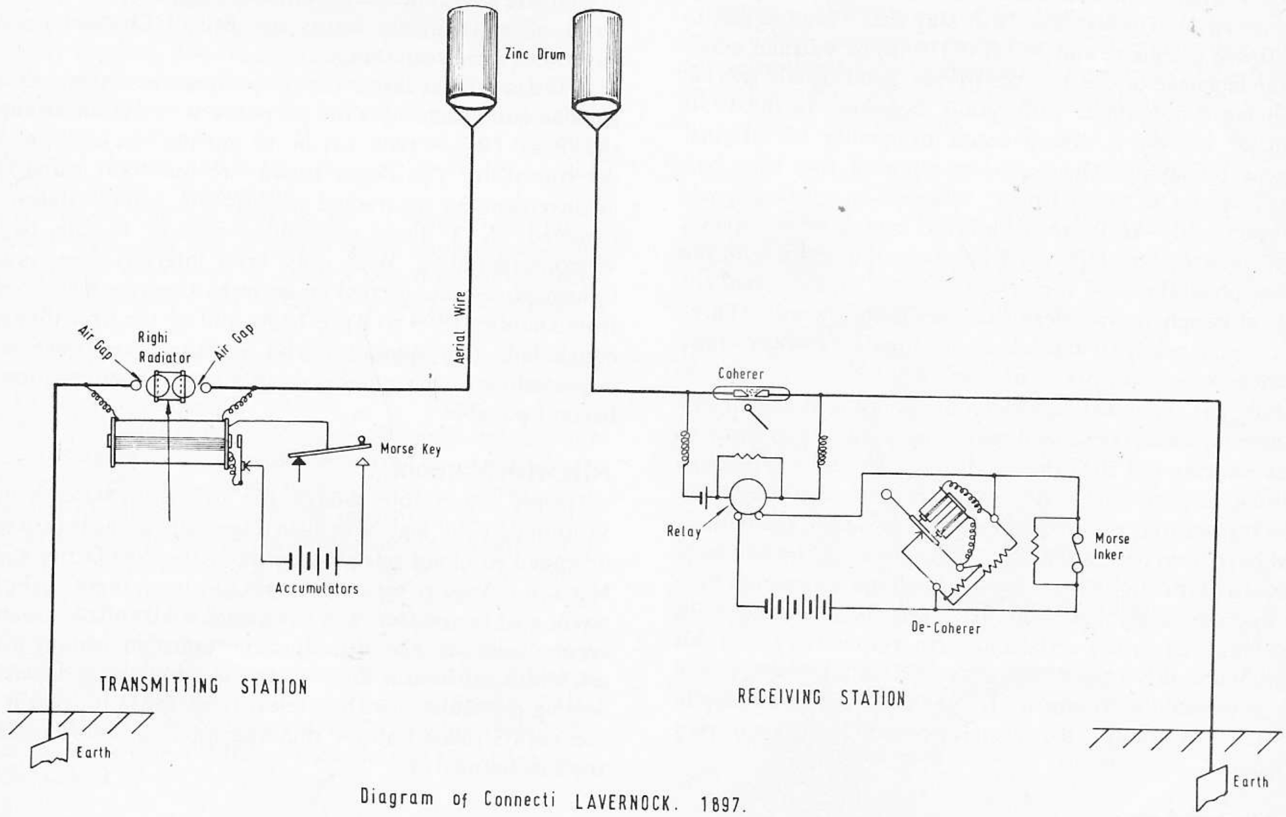
Thursday 13th May

'The great day for Flat Holme signals. I started at 7 a.m. and fitted a new copper earth wire in lieu of the iron earth. I sent and received good signals on both systems between 12 and 1.45 p.m. The first half hour of Vs were on a paper strip on the inker; the second, "so be it, let it be so", and the third, "it is cold here and the wind is up". This message was posted to the Kaiser by Professor Slaby.'

'In the afternoon Mr. Marconi came over and tried some adjustments; Mr. Taylor came with him and did a little transmitting but, as I sent the best sentences between 12 and 2 p.m. I returned to those adjustments and sent them the following:

'How are you?'	repeated
'It is hot'	repeated
'Marconi'	repeated
'Go to bed'	repeated
'Go to Hull'	repeated

*The typed and edited version of the diary of the late G. S. Kemp prepared by him for the Marconi Company in about 1930



Circuit diagrams of the transmitter and receiver used during the Lavernock trials (From report by the engineer in chief, GPO 1903)

MARCONI CENTENARY

'So be it' repeated
'Tea here is good' repeated
Nine similar sentences follow.

The tests were resumed the following morning. A motor-driven commutator and a Vrill break were tried, but with no marked improvement on the previous day's results.

Saturday 15th May

'I dismantled the Marconi transmitting apparatus on Flat Holme, leaving it at Penarth, and then arranged for a steamer to Brean Down on Monday'

Transmission across Bristol Channel

This is the first mention in any of the records of the proposal to attempt to transmit right across the Bristol Channel from Lavernock to Brean Down on the Somerset coast. It leaves the impression that it was a sudden 'on the spot' decision, inspired in all probability by the success of the Lavernock–Flat Holme experiments. Preparations continued over the weekend, with Kemp assembling the Marconi transmitter on the top of the cliff at Lavernock. However, Monday brought bad weather, and Kemp noted that it was too rough for the receiver party to land at Brean Down.

Kemp himself remained at Lavernock to operate the transmitter, and just how the receiver party eventually reached Brean Down is not evident from the surviving records. There is no record either of the names of those in the receiver party, or of exactly what they received; but in his contemporary diary Kemp noted on Tuesday the 18th May that 'Good signals to Brean Down using kite and 300 ft (91·4 m) of 4-strand wire'.

In the language of the day, the phrase 'good signals' was far from being synonymous with 'good messages'. In the 1930 version of his diary, Kemp seems to qualify his original comment by saying 'The engineers reported that they had received signals at Brean Down'. Whether or not the signals were exactly 'Q5' (fully readable), it is evident from Gavey's report[3] that the Post Office officials were impressed with the inherent possibilities of the system. Signals, of sorts, had got across, although it was clear that, in Gavey's words, 'There was . . . . still much to be desired in order to convert crude appliances into good working devices'.

In fact, the apparatus that Marconi was using at the time of the Lavernock trials possessed two fundamental faults, one in the transmitter and the other in the receiver and it is perhaps surprising that the results obtained were as good as they were. At the transmitter, the frequency of the principal oscillations would have been determined by the diameter of the two large brass balls of the Righi oscillator and the frequency would have been approximately 500–800 MHz. But the two outer balls were connected to the aerial and earth, respectively, and this system, while the spark gaps were sufficiently ionised, would have possessed a resonant frequency of approximately 2–3 MHz. Inevitably, the system would have been very inefficient.

Fundamental error

Similarly at the receiver a fundamental error in principle was involved by interposing the coherer directly in the lead connecting the aerial and earth. In its sensitive condition, a coherer possesses a very high resistance, and by locating it directly in the aerial–earth circuit, it clearly interrupted the continuity of the oscillatory system. While there were a number of factors that mitigated this error, it was undoubtedly one of the major factors that contributed to the capricious and inconsistent results that were so often experienced.

This historic series of experiments across the Bristol Channel came to a close when Kemp noted the following in his diary:

Saturday 29th May

'Packed up and returned to Paddington by the 10.37 p.m. train from Cardiff, arriving at Paddington at 3.30 a.m. on Sunday morning. We stowed all the apparatus in the cloak room'.

However, this was not quite the end of the association of Lavernock and Brean Down with the early development of wireless telegraphy.

Only a few weeks after the completion of the trials, Marconi and his associates registered their company, the Wireless Telegraph and Signal Company. An event that unfortunately led to the Post Office breaking off all collaboration with Marconi. The Secretary of the Post Office and his legal advisers took the view that it would be improper for the Post Office to spend further time and money in developing an invention, the patent rights in which were held by a public company. As a result, the engineer-in-chief was formally instructed that 'for the present Mr. Marconi could not take part in any Post Office experiments whatever'.

Subject dropped

For almost two years the subject of wireless telegraphy was dropped completely within the Post Office, but by the autumn of 1899 it became known that Marconi was achieving ranges of approximately 60 miles, and, to 'keep in the swim', it began to seem desirable for the Post Office to pick up the threads once more. An immediate incentive was provided by an approach from an Hungarian inventor, Bela Schaefer, who offered a receiver that might have provided an alternative to that described in the Marconi patent. Arrangements were accordingly made for a thorough test of the Schaefer detector, and to compare it with the coherer method of reception in a further series of experiments across the Bristol Channel between Lavernock and Brean Down.

In the event, the instability of the Schaefer detector showed it to be quite useless for the purposes of communication, but the Post Office now began to pursue the subject with determination. The Brean Down site was soon found to be inconvenient for protracted experiments, and the station was removed to a more accessible location in the bay of Weston-super-Mare. With only brief intervals, experimental transmissions were carried on between Lavernock and Weston from October 1899 to April 1900, and by the time they were concluded, the apparatus and circuitry had been much improved, so that regular and fairly easy communication had become possible.

Rift with Marconi

Deeply regrettable though the rift with Marconi in the autumn of 1897 may have been (especially in the way in which it tended to cloud relations between the Post Office and the Marconi Company for many years to come), there can be little doubt that the two series of Lavernock trials and the associated events were of the utmost importance in leading to the establishment within the Post Office of a strong department dealing particularly with wireless telegraphy. Indeed, it is to the events related above that the modern radio branch can trace its foundation.

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