Radio Communication

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Classic Paper

I very much appreciate the honor of being able to read this address* before members of the American Institute of Electrical Engineers and of The Institute of Radio Engineers, especially as I know that in America radio science is more deeply investigated, more universally understood, and more generally utilized than in any other country on earth.

I also cannot but cherish always the recollection that the American Institute of Electrical Engineers was the only technical and scientific body which more than twenty-five years ago first believed in me and endorsed my statement that in December, 1901, I had succeeded in getting the first radio signals across the Atlantic Ocean, the first distinguished and authoritative Society enthusiastically to celebrate the event and to extend to me their generous support and valuable encouragement.

It is a further satisfaction to me to realize that as a result of recent discoveries and inventions the subject of radio communication is today attracting more world-wide interest and attention than any other advance of physical science and of electrical engineering.

In the early days of "Wireless," when electromagnetic waves were first beginning to be employed for practical purposes, we spoke only of "wireless telegraphy," or "radio telegraphy," but with the advance of the art these waves have been more and more widely utilized not only for telegraphy but also for telephony and broadcasting, direction-finding at sea and in the air, for the control of mechanisms and the ignition of explosives at a distance, principally for war purposes and, more recently, also for the transmission of line drawings, photographs and facsimiles, and finally, for television, which is now, I believe, finally emerging from the laboratory stage.

I hope I shall not be thought too visionary if I say that it may perhaps be possible that some day electromagnetic waves may also be used for the transmission of power, should we succeed in perfecting devices for projecting the radiation in parallel beams in such a manner as to minimize their dispersion and diffusion into space.

The achievements and possibilities of radio have already become so vast, so far-reaching, and their theory so complex and undergoing at the present time such a bewildering process of evolution that you will easily understand that, did I not confine myself to the generalities of even a small part of my subject, I would find it quite impossible to keep the length of my address within practical limits.

It would also be quite useless for me to endeavor to describe at any length the general achievements and utility of radio in a country where so very much is already known of this art and science and where such gigantic strides are being made in its practical application and scientific development.

I shall, therefore, necessarily be unable to dwell upon the valuable research work on the now all-important subject of short waves which has been carried out here, particularly by the engineers of the Radio Corporation of America, but this has already, in part, been described in an admirable paper by Messrs. H. E. Hallborg, L. A. Briggs, and C. W. Hansell, which was published in the June number of the PROCEEDINGS OF THE INSTITUTE OF RADIO ENGINEERS.

I, therefore, propose to limit myself to referring briefly to the development and utilization of this latest and most important evolution of radio science, which has already had the effect of compelling us to modify radically our views in regard to the practice and theory of long-distance transmission.

For this purpose I shall confine myself principally to a brief historical sketch of the investigations carried out by myself and my assistants on the subject of short waves and to describing some of the strides that have already been made in their application to radio communications over long distances.

I feel that I must here repeat my belief that we are as yet far from being able to assert that radio is based on well-understood foundations, unless, of course, we should go back to the long-distance technology of the past which, to my mind, has become more or less obsolete when applied to present-day long-distance practice.

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Whatever degree of perfection may have already been achieved in the design and construction of "wireless" stations and radio apparatus, we must realize that we still know too little of the true mechanism governing the propagation of the waves, and of the properties and behavior of the space which they traverse.

Speaking generally, it seems to me that latest developments tend to show us that four or five years ago radio engineers thought they knew much more about the subject than, perhaps, we think we know today. Laws and formulas were announced and accepted showing which wavelengths were best adapted for various distances for both day and night transmission and indicating what amounts of power would be necessary in order to enable us to communicate with a fair degree of regularity over any given distance. But, unfortunately, the logical application of these laws and formulas brought us to the necessity of employing for long-distance work such enormous and expensive antenna-systems and such large amounts of power as to make radio transmission so costly in capital expenditure and operation that it would hardly compete economically with modern cable and land lines.

The study of what are now termed short electrical waves can be said to date from the time of the discovery of electromagnetic waves themselves, that is, from the time of the classical experiments of Hertz and his contemporaries nearly forty years ago: for Hertz used short waves in his laboratory when he first conclusively proved that electrical waves existed, and that they were subject to the same laws as the waves of light in regard to reflection, refraction, diffraction, interference, and speed of propagation.

I might also, perhaps, recall the fact that in my own earliest experiments thirty-one years ago I was able to demonstrate the transmission and reception of intelligible signals through space over a distance of 1 3/4 miles by means of a directive system employing waves of only about 1 meter in length, whereas at that time, by means of the antenna or elevated wire system employing much longer waves, I could only, curiously enough, get signals over a distance of about one mile and a half.[1]

The progress which has, however, been made subsequently with the long-wave system was so rapid and so spectacular in regard to distance, and the results available so easily applicable to the urgent needs of shipping, that it diverted all research from short waves, especially as it appeared, as indeed was proved, that by efficiently utilizing waves longer, and longer than those of about 150 meters—which were the first to be employed for any considerable distance—the ranges over which it was possible to communicate were steadily increased and the absorption caused by the effect of sunlight decreased and later, by the use of the longest waves, finally overcome.

This neglect of short waves was, I think, regrettable, for, notwithstanding the intense radio research that has been carried out in most countries for the last twenty-five years at least, it has been left to only recently to discover that these waves possess most valuable and unsuspected qualities in regard to world-wide transmission and that they are capable of results unobtainable by the lower frequency system which, up to almost the present day, has held the field for all long-distance radio communication.

Since my early experiments carried out in 1896–97 and for a very long period of years afterward, no serious research work was carried out, or at least published, so far as I can ascertain, in regard to the application of very short waves to radio purposes.

Research along such lines did not appear promising: short waves were not easy to produce or to detect with the means then at our disposal, and up to recent times the power that could be put into them was small. This, together with the erroneous but general belief of the high attenuation of the waves over even short distances, deterred experimenters from entering this new field of research.

Some years ago, during the World War, I could not help feeling that we had perhaps gotten into a rut by confining all our researches and all our tests to long waves; that is, to waves of hundreds of thousands of meters in length; especially as I realized that, in accordance with theory, it would be practically possible only by the use of short waves to project the radiation in narrow beams in any desired direction instead of allowing it, as had always been done, to spread and dissipate in every direction.

I was greatly impressed by the advantages that such a system might possess for point-to-point communication, by the possibility which it would afford of reducing tapping and interference even if several stations were worked in the same area, and also by the possibility of a better and more logical utilization of the energy radiated from the transmitter.

My doubts were as to whether atmospheric absorption, the interposition of obstacles, and the curvatures of the earth would not result in always limiting the distance of useful operation to a few score of miles, but I hoped that through the concentration of energy brought about by the utilization of efficient reflectors and, perhaps, by some unknown yet beneficient effect of the upper conducting layer, it might, nevertheless, be possible to effect communication across not inconsiderable distances.

This line of research was taken up by me in Italy early in 1916, and in subsequent development work during that year and afterwards I was most valuably assisted by Mr. C. S. Franklin, of the Marconi Company.

Mr. Franklin, under my direction, followed up the subject with great thoroughness, and the results of several years of our investigations were described by him in a paper read before The Institution of Electrical Engineers in London on the 3rd of May, 1922, and also by me in an address delivered before a joint meeting of the American Institute of Electrical Engineers and The Institute of Radio Engineers in New York on the 20th of June of that same year.

The results obtained up to that time definitely convinced us of the enormous advantage to be gained by the use of suitable reflectors at both the transmitting and receiving stations. The tests were carried out with very small power

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[1] See paper read before the Institute of Electrical Engineers in London, March 2, 1899.

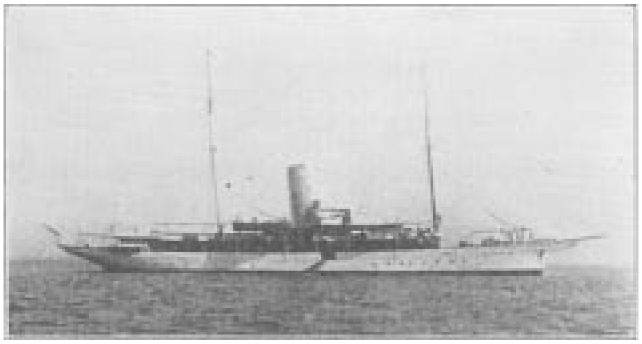

Fig. 1. Senatore Marconi's yacht *Elettra*.

and with waves from between 2 and 15 meters in length, up to distances of about 100 miles; but I should point out that at that time there was nothing to indicate to us that these distances constituted the limit range of the waves thus employed. We did, however, ascertain by a number of careful measurements that the energy received when suitable reflectors were used at both the transmitting and receiving ends could be 200 times that of the energy received when no reflectors were employed.

Systematic tests, the object of which was to ascertain the range and capabilities of short waves over varying distances, were commenced by myself and Mr. C. S. Franklin in the spring of 1923 between a small experimental transmitting station situated at Poldhu in Cornwall and a special receiving station installed on the Steam Yacht *Elettra*.

The results obtained from these tests went far to convince me that short electric waves possessed qualities which, up to that time, had remained unknown and that this new line of investigation was opening up a vast field of profitable research full of undreamed-of-possibilities.

The principal objectives aimed at in the experiments carried out between Poldhu and the S. Y. *Elettra* were:

1) To ascertain the day and night ranges and reliability of signals transmitted on wavelengths of less than 100 meters, possibly over considerable distances, with or without the use of reflectors or directional devices;
2) To investigate the conditions which might adversely affect the propagation of short waves, such as the interposition of land or mountains between the two stations, and also how the night or day ranges varied with the wavelength employed and the power utilized;
3) To investigate and determine, if possible, the angle and spread of the beam of radiation emitted when employing a transmitting reflector, especially with a view to the possibility of establishing long-distance directional services.

A wavelength of approximately 97 meters was first employed, with a power of 12 kilowatts in the aerial, and during our journey, in the course of which ports and places in Spain, Morocco, Madeira, and Cape Verde were touched, it was ascertained that, with the power and wavelength employed, signals could be reliably received during daylight up to distances of 1250 nautical miles.

In carrying out these tests I first noticed that it is by no means correct, in dealing with waves of approximately 100 meters, to refer to distances covered during daylight as "day ranges," because the strength of the signals which could be received varied definitely and regularly in accordance with the mean altitude of the sun over the space or region intervening between the two stations.

The night signals came in always with great strength and remarkable regularity up to the maximum distance to which the yacht was able to proceed on that occasion, which was as far as the Cape Verde Islands, situated at 2320 nautical miles from Poldhu. The strength of the signals received here at night left no doubt in my mind that their practical range was very greatly in excess of that distance.

I believe that I am right in saying that up to that time the general impression prevailing among most technical experts in regard to the behavior of very short waves was:

1) That their range during day-time would be very short.
2) That their night ranges, although occasionally considerable, would be exceedingly variable and freaky and subject to long periods of "fading," rendering their use altogether too unreliable for practical purposes in long-distance commercial working.
3) That any considerable stretches of intervening land, especially if mountainous, would greatly reduce the distance over which it might be possible to communicate.

Our 1923 tests brought me absolutely and definitely to the conclusion that such opinions and beliefs were wrong in so far as they might concern the behavior of waves of about 100 meters in length, for we discovered:

1) That the daylight ranges were not by any means inconsiderable and, in fact, proved to be much greater than had been anticipated.
2) That the night working was very much more reliable than had been believed possible; that "fading" was not at all so serious as had been anticipated and that the great strength of signals received indicated that the night range would probably be much greater than anyone, myself included, had ever before expected or anticipated.

Moreover, a fact of great practical value was also observed, and this was that even in the tropical countries the atmospheric electrical disturbances, termed "static" or "X's," were invariably much less troublesome and severe when receiving on short waves than those experienced with the much longer waves which, up to that time, were being exclusively used for all long-distance work.

The results of these tests were set forth in a technical report drawn up at the time, and were also described in detail and published in a paper which I read before the Royal Society of Arts in London on the 2nd of July, 1924. In that paper I ventured to predict that it would be possible by means of short wave directive stations of small power to send and receive a far greater number of words per 24 hours over world-wide distances than would be practicable by means of the existing or the then proposed powerful and expensive long-wave stations. This, at the time, may have seemed a bold statement, but I felt sure it was going to be justified by results.

Further tests and experiments were carried out in February and March, 1924, with the object of determining the maximum practical ranges of these waves, and we found that, while the day range of a 92-meter wave was about 1400 miles, i.e., greater than the day range of a 97-meter wave, strong and fairly reliable signals could be received during the dark or semidark hours not only in the United States but also in Australia; that is, over worldwide distances.

The results were so encouraging that I was tempted shortly afterwards to try a telephony test to Australia, which was quite successful (30th of May, 1924).

In August and September of the same year another series of tests was carried out between the Poldhu station and the S. Y. *Elettra*, with the object of studying the behavior of still shorter waves over long distances, in order to ascertain whether it might not be possible to overcome in some measure at least the curtailment of the hours of working brought about by the effects of daylight, for, of course, we realized that this limitation of the period of operation to practically only the hours of darkness constituted the principal drawback to the possible general adoption of these waves for commercial and practical purposes.

Experiments were, therefore, conducted over varying distances with four wavelengths of 92, 60, 47, and 32 meters respectively.

These tests enabled us to discover the important fact that for long distances the daylight range steadily increased as the wavelength was reduced below 92 meters, the 32-meter wave being received with ease all day at Beyruth, Syria, over a distance of 2100 miles, while the 92-meter wave began to fail over this track during daylight at a distance not much in excess of 1000 miles.

During these tests the 60-meter wave appeared to be slightly better than the 92-meter wave during daylight, the 47-meter wave still better, and the 32-meter wave very much better.

From the result of these experiments we naturally presumed, and later experience confirmed our anticipation, that still shorter wavelengths would show still greater daylight range and further tests carried out by ourselves and other workers not only proved this to be a fact but also showed that very short waves, while being capable of working over the greatest distances during daylight, had but a comparatively short and unreliable range of action during darkness.

This discovery, which has brought about a reversal of what was noticed in regard to wavelengths longer than 200 meters, apart altogether from its enormous practical importance, gives rise to scientific questions of the highest interest and importance and requiring theoretical explanation as to how these waves can travel, even right around the world.

I do not intend, on this occasion at least, to indulge in any theoretical hypothesis or theory, as I much prefer to confine myself to the description of observations and of what I believe to be facts, leaving to others to arrive at the most valuable theoretical inferences which may be deduced from them.

In October, 1924, transmission tests were carried out on a wavelength of 32 meters from England to specially installed receivers at Montreal, Long Island (New York), Buenos Aires, and Sydney (Australia), and it was at once found possible to transmit messages when utilizing only 12 kilowatts or less at the transmitter to all these distant places even when the whole of the great circle track between them and England was exposed to daylight.

With Australia, however, it is only possible to have a track from England completely exposed to daylight for 2 or 3 hours at a time, and, furthermore, the scientific aspect of the test is complicated by the fact that the waves may have several ways of getting round the earth with comparative ease, as a large part of Australia is not very far from the antipodes of England.

The Australian tests showed, however, that it was possible to get through for about 23 1/2 hours out of the 24.

Numerous other tests were carried out with various far-distant countries, including Japan, from a small power station at Chelmsford, England, which utilized only about *one-fifth of a kilowatt* of antenna energy, the object being to test still shorter waves. It was thus noticed that a wavelength of 10 meters was about the shortest which enabled signals to be detected at Sydney in Australia, and then only during the time when practically the whole of the great circle track between England and Australia was exposed to daylight.

I should point out that these particular tests were carried out without reflectors at either end, the sole object being to ascertain the range and general behavior of these waves over long distances.

In the directive experiments I carried out in Italy and in England, in 1916 and subsequent years, the reflectors consisted of a number of vertical wires of suitable length parallel to the antenna and spaced around it on a parabolic curve, of which the transmitting or receiving antenna constituted the focal line. The aperture of the reflector was always made to be not less in width than 2 or 3 wavelengths.

Suggestions for utilizing reflectors of this kind were made by Brown in 1901 and by DeForest in 1902, but many essential conditions necessary for efficiency were apparently not realized at that time, which fact may explain why no practical application of their arrangements was made.

Since 1916 various patents have been taken out by myself, Mr. C. S. Franklin, and other workers for reflectors and directive antennas, but in the commercial shortwave stations which have been constructed by the Marconi Company for the British and other governments, and which are now in operation, an arrangement patented by Mr. C. S. Franklin is employed.

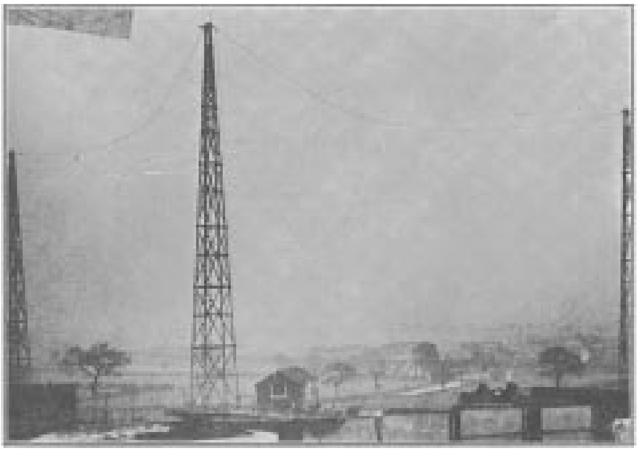

Fig. 2. Parabolic reflector: Hendon.

In this arrangement the antennas and the reflector wires are disposed so as to constitute grids parallel to each other, the aerials being energized simultaneously from the transmitter at a number of feeding points through a so-called "feeder system," and in such a manner as to meet the condition that the phase of the oscillations in all the wires is exactly the same.

It has been proved by calculations confirmed by experiments that the directional effect of such an arrangement is a function of its dimensions relative to the wavelength employed.

A similar system of aerials and reflecting wires is used at the receiving stations.

For a more complete account of our investigations, together with a more detailed description of the general principles on which my short-wave directional system is based, and also in regard to the apparatus employed, I would refer you to my papers read before the Royal Society of Arts on the 2nd of July and the 11th of December, 1924, to the paper read before the American Institute of Electrical Engineers and The Institute of Radio Engineers in New York on the 20th of June, 1922, to my "James Forrest" lecture delivered before the Institution of Civil Engineers in London on the 20th of October, 1926, to my paper "Le Radiocomunicazioni a Fascio" published in the Nuova Antologia of Rome in its issue of the 16th of November, 1926, to Mr. C. S. Franklin's paper read before the Institution of Electrical Engineers in London on the 3rd of May, 1922, and also to an article by Dr. J. A. Fleming which appeared in the *Wireless Engineer* of London in July of this year.

As I have already said, it has been proven long ago by calculations confirmed by observations that the directional effect of a radio reflector is a function of its dimensions in relation to the wavelength employed. Hence it follows that the dimensions of the reflector can be reduced proportionately to that of the wavelength and, therefore, that the cost is much lower and the space occupied much smaller for wavelengths of, say, 20 meters than for wavelengths of 90 or more meters.

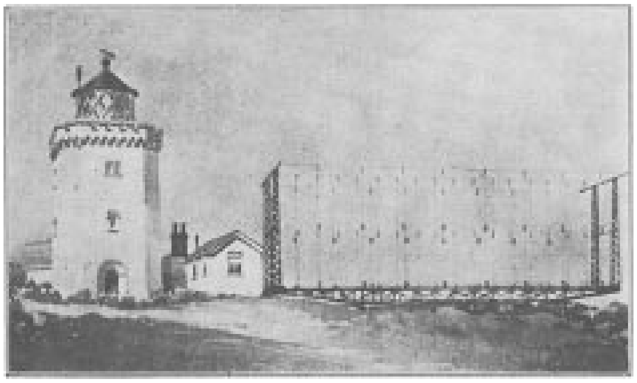

Fig. 3. South Foreland revolving beam.

The same calculations show us that the dimensions of a reflector for really long waves would be so enormous as to render its construction impracticable and impossible both for economic and engineering considerations.

Early in 1924 the British Government began to consider seriously proposals made by the English Marconi Company for the employment of the short wave directive system, now generally known as the "beam system," in order to satisfy the long-expressed desire of the dominions for a rapid and efficient means of radio communication with the mother country, and in July of that year a comprehensive agreement was entered into between the British Post Office and the Company for the construction of radio stations on the beam system in England and in the British Dominions, to be operated in England by the Government, which would be capable of ensuring a high-speed commercial service from and between England and Canada, South Africa, India, and Australia.

This contract stipulated that the transmitting stations should dispose of a power of 20 kilowatts to be delivered to the anodes of the tubes used for generating the oscillations, that the aerial and reflector system was to be designed so as to concentrate the emitted waves within an angle of 15 degrees on either side of the axis of transmission, the energy emitted beyond this angle not to exceed 5 percent of that on the axis, the receiving stations to have a similar aerial and reflector system designed to have its maximum receptivity in the direction of the corresponding station.

The conditions in regard to the speed of working were exceptionally stringent and severe.

The stations for corresponding with Canada were to be capable of accurately sending and receiving at the same time to and from Canada at the rate of one hundred five-letter words per minute (exclusive of any repetitions necessary to secure accuracy), during a daily average of eighteen hours.

The stations for communicating with South Africa were to be capable of maintaining the same daily rate of speed and accuracy for eleven hours.

The stations working with India had to meet the same requirement for twelve hours and those working to and from Australia for seven hours daily.

The Company was to give the Post Office a practical demonstration of actual working for seven consecutive days, which would prove to the satisfaction of the Gov-

Fig. 4. Bodmin beam station. South African masts.

ernment engineers that these severe conditions could be fulfilled.

In November of last year the Canadian circuit passed its official test, and in March, May, and August of this year the Australian, the South African, and the Indian Stations also completed their official communication tests and are now carrying on an important commercial public service which has already had the beneficial effect of bringing about a reduction of the telegraphic rates between England and her most important dominions.

It has been found that, in regard to the stations communicating with Australia, South Africa, and India, a daily average of over twenty hours of high-speed communication is attainable, and that the spread of the beam is much narrower than had been specified in the Government requirements.

These results, which are truly unprecedented in the history of radio communication, have been of the greatest possible satisfaction to myself and my co-workers, because they go to prove that our faith in the new system, which for years we upheld in the face of much scepticism and criticism, was not altogether misplaced.

The British Government has already expressed through its executive officials its high appreciation of the success of the new radio system.

Colonel T. F. Purves, Engineer Chief of the British Post Office, in a letter of the 26th of August last addressed to the Marconi Company stated:

“All four stations erected by your Company providing direct telegraph communication with Canada, South Africa, India, and Australia have now been completed. It is with pleasure that I take this opportunity of offering my congratulations on the high degree of technical skill and resource displayed in successfully surmounting the many novel difficulties encountered in the work of carrying to fruition this great new development of the radio art.”

The Rt. Hon. W. Mitchell-Thomson, British Post-Master General, also wrote on the 5th of October as follows:

“The introduction of the beam system will have far reaching effects in reducing the cost of long-distance communications by wireless telegraphy and I cordially congratulate your Company on a notable achievement.”

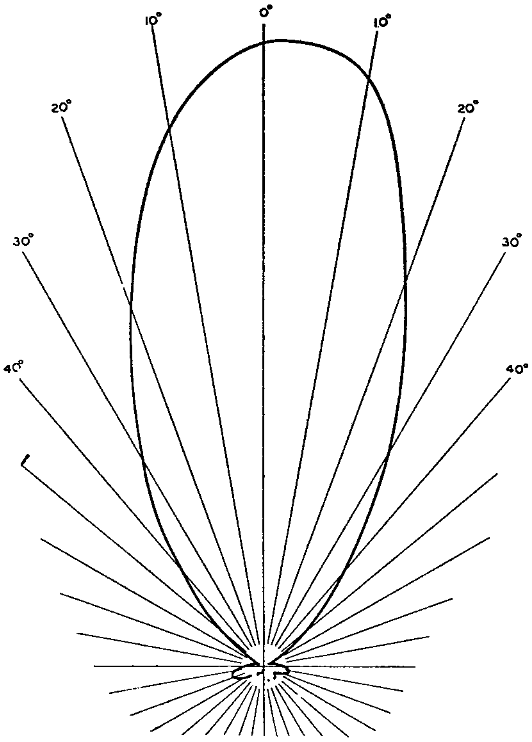

Fig. 5. Polar curves, Hendon. Reflector, 28 meter aperture, 4.3 meter wave. Measured on circle of 31 meter radius.

The English stations for working with Canada and South Africa are situated at Bodmin, and at Grimsby for working with Australia and India; the receiving stations being respectively at Bridgewater and Skegness.

The corresponding stations in Canada are at Drummondsville and Yamachiche not far from Montreal; in Australia at Bellan and Rockgank, near Melbourne; in South Africa at Klikheuvel and Milnerton, near Cape Town, and in India at Kirkee and Dhond, near Poona.

The stations are all worked by what is termed “remote control” through land lines from the Central Telegraph Office in London, and the received signals are strong enough to work high-speed recording and even printing instruments also in the same office in London.

In India and in the other dominions the same system of direct control is in operation between the Telegraph Offices in Montreal, Melbourne, Cape Town, and Bombay with the corresponding radio sending and receiving stations.

The aerial and reflector system at each station is supported by a row of masts so arranged that the great circle bearing to the distant station with which each particular aerial system is intended to communicate is at right angles to the line of masts. The design of the aerial and reflector system is substantially the same at each station. The masts are spread at a distance of 650 feet from each other.

In the case of the Canadian, South-African, and Indian services, each reflector and aerial system is suspended on a line of five lattice steel masts, each 287 feet high, but in the case of the Australian stations where a single wave is being

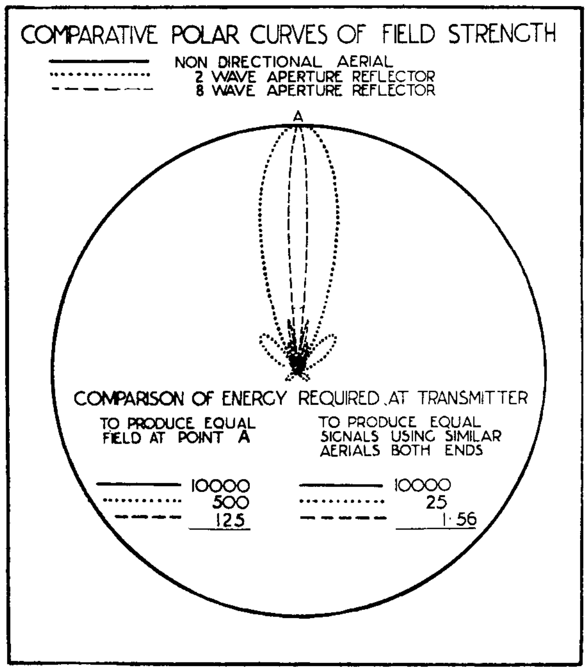

Fig. 6. Comparative polar curves on beam and round transmitter.

used there are only three masts and their height is 260 feet.

The Australian system has the further difference that it is constructed with an aerial system on either side of a central reflector so that it is capable of transmitting to Australia in the direction of either the easterly or westerly great circle. This arrangement has been made as a result of the experience which we gained when carrying out our preliminary short-wave tests with Australia at the beginning of 1924.

It was then found that the position and altitude of the sun had an effect as to which route the waves preferred to follow, and that during the morning period in England the waves preferred to travel from England to Australia in a westerly direction across the Atlantic Ocean following the great circle along the longest route which is approximately 14 000 miles; whereas, during the afternoon and part of the night period the waves travel best in an easterly direction over Europe and Asia following the shortest great circle route which is about 10 000 miles. It is the practical application of this discovery which has resulted in the construction of the Australian transmitters and receivers so that transmission or reception can take place in either direction as required.

In all the sending stations the radio-frequency current is conveyed to and from the aerials through what I have already referred to as a "feeder system" consisting of concentric copper tubes air-insulated from each other to reduce loss. The outer tubes are earthed and carried on iron standards driven into the ground. The inner tubes, which constitute the conductors, are kept in position and insulated from the outer tubes by means of porcelain spacing insulators. The length of feeder tube from the transmitter to each individual aerial wire in each aerial system is made to be exactly the same.

Thermionic tubes are used to generate the extra high-frequency oscillations and oil-cooled valves or tubes are employed on the main circuits in preference to water-cooled tubes because in shortwave work oil is easier to handle besides being itself an insulator.

The wavelengths in meters and frequencies in kilocycles used are:

For communicating with:

Canada	16.574	18 100
	32.397	9260
Australia	25.906	11 580
South Africa	16.146	18 580
	34.013	8820
India	16.216	18 500
	34.168	8780

It is obvious that I am not even attempting to give anything like a complete description of these stations, nor have I said anything in regard to the buildings, power-plant, switchboards, rectifiers, controls, keying-systems, etc. To describe these important items and the receiving apparatus and stations together with an even brief account of the engineering and other difficulties encountered would require much more than one lengthy paper.

Other beam stations in England are nearing completion for the purpose of working high-speed services to corresponding stations erected by or in cooperation with the Radio Corporation of America in the United States and also with South America; and similar stations have already been erected and are now carrying on a public service between Portugal and many of her distant colonies.

Mr. C. S. Franklin has to his credit the successful design and testing of most of the arrangements and devices employed, especially on the technical and scientific side; and Mr. R. N. Vyvyan for those on the engineering side. I hope they may soon be able to find time to prepare and publish a more complete description of these stations.

The commercial continuous working of these long-distance services over a period of many months has made possible the collection of observations of great scientific interest, and the carrying-out of further tests the results of which are, perhaps, quite novel in the history of long-distance radio.

One of them is in regard to electrical atmospheric disturbances generally termed static or "X's."

I think we all know that static has all along been the bugbear of radio, but one of the most salient facts that we have noticed in working long-distance services by means of short waves is that, particularly when receiving reflectors are employed, static has been generally conspicuous by its absence, and, when noticeable, the signal strength has mostly been well above the disturbance strength-level of static. Thunderstorms in the vicinity of the receiving stations occasionally interfere with working when they happen to be inside the angle of receptivity of the receiving reflectors, but not even then when they are at some considerable distance.

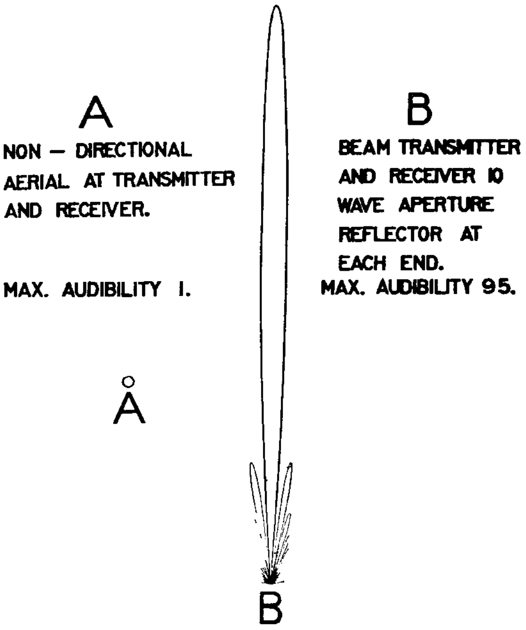

Fig. 7. Polar diagrams illustrating relative audibility at equal range and with equal transmitting power, assuming the wavelength and other conditions are the same.

In working the high-speed receiving stations situated near Bombay throughout the whole of the East-Indian summer and during the monsoon period, interruption or interference with the signals received from England due to static has been of very rare occurrence.

I feel quite confident that our old enemy of static interference no longer exists as a serious hindrance to the working of high-speed radio as carried out by the beam system.

I fully realize that this is a bold statement to make, but I feel quite confident that I am right in making it.

The variations, or rather, the attenuation of signal intensity, now termed "fading" is the one, and I believe the only really serious difficulty with which we still have to contend.

Fading has been a marked feature of long-distance radio, especially when short waves are employed, and although in my experience fading appears to be worse on wavelengths between 200 and 1000 meters it has often proved to be serious on the very short waves now utilized by the beam system.

According to my experience, the use of reflectors has the advantage of diminishing the bad effects of fading. This is due, no doubt, to the very considerable increase of the average strength of signals obtained by the utilization of the directional system which, thereby, increases the margin of readability of received signals enabling them to be still recorded or read through most of the fading periods.

I have been able to make some very interesting observations in regard to the phenomena of fading from the working of the short-wave beam system for world-wide communication of which England is now the center.

Fading has always been more frequent and more severe on the England–Canada circuit than on any of the others. It may be noticed that our Canadian service is also our shortest distance service, that it is mostly across the sea and that the Canadian station is the one which happens to be nearest to the north magnetic pole.

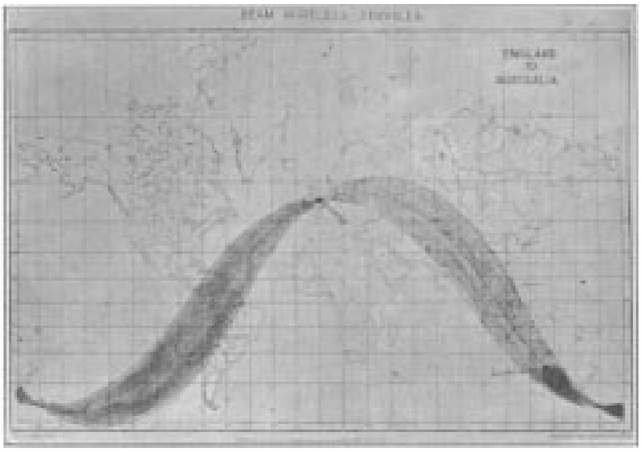

Fig. 8. Beam services.

Some interesting suggestions on the "Correlation of Radio Reception with Solar Activity and Terrestrial Magnetism" have been set out in a paper by Mr. Greenleaf W. Pickard, published in the PROCEEDINGS OF THE INSTITUTE OF RADIO ENGINEERS, vol. 15, no. 2, of February of this year.

It frequently occurs that when the Canadian communication fades out for some hours on end, the other services to Australia, India, and South Africa, which use similar wavelengths, continue working with undiminished efficiency. It has also been noticed that the times of bad fading practically always coincide with the appearance of large sun-spots and intense aurora-boreali usually accompanied by magnetic storms and at the same periods when cables and land lines experience difficulties or are thrown out of action.

We have also frequently noticed that during these periods signals could be received on a shorter wavelength than the one usually employed, often on a 16-meter wave when a 26-meter wave would not come through.

As is now generally known, very short waves, of 16 meters and under, can be better received at long distances by daylight and in summer time than during winter or at night, and we also know that very long waves are not affected by daylight.

It may be that, on certain occasions during periods when sunspots and auroras are prevalent, conditions due to the increased ionization of the atmosphere at a certain height are prevalent, resulting in the lowering of the ionized stratum which would produce an effect equivalent to what we might term "intensified daylight."

Professor Elihu Thomson in a lecture delivered in London during 1924[2] stated that it was his opinion that extensive auroral display was coincident with the existence of exceptional areas of disturbance in the sun, and he also referred to the probability under such circumstances of a decided elevation of charge, or potential, of the outer conducting layer 50 or 60 miles above the earth's surface.

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[2] "James Forrest." Lecture delivered before The Institution of Civil Engineers in London on the 8th of July, 1924.

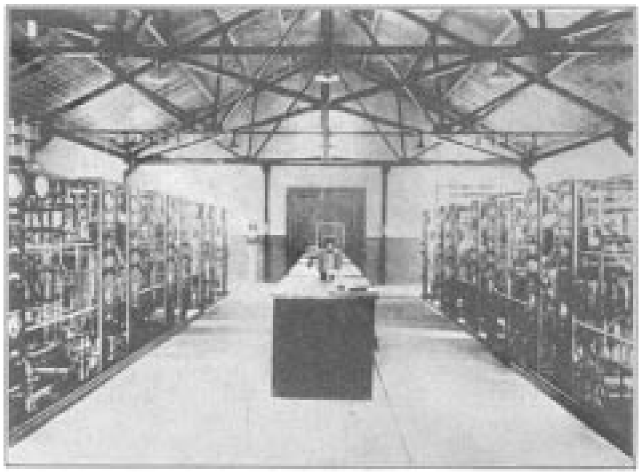

Fig. 9. Bodmin transmitters. Left, Africa; right, Canada.

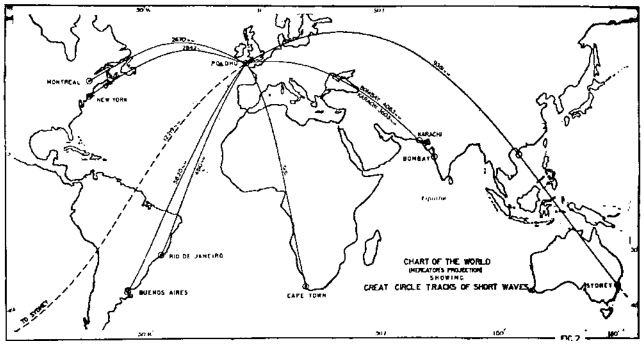

Fig. 10. Map of the world. Great Circle Tracks.

The phenomenon of fading is now being investigated by many workers, and progress is already being made in overcoming the difficulties which have been experienced in maintaining an absolutely continuous service between distant stations.

Time will not allow me to deal with this all-important subject which would necessarily require my referring to lengthy papers and reports and the publication of data which may still need experimental confirmation over protracted periods.

I shall, however, make a very brief reference to the subject of “skip distances.”

This phenomenon, the study of which has been taken up since the advent of short waves, has been very carefully investigated by Mr. A. Hoyt Taylor and set forth and discussed by him in several admirable papers.

It is now, of course, well known that a wave of about 15 meters can be received with much greater strength and regularity during day time at distances about or over 5000 miles than at distances of the order of a few hundred miles.

My experience, which I wish to record because it differs somewhat from the conclusions arrived at by Mr. Hoyt Taylor, is that when receiving on my yacht, even with land intervening between the two stations, there are no distances at which I have ever found zones of absolute nonreception, but that I have noticed zones where signals were weak and variable and where reception conditions closely resembled those prevalent at the normal ranges of the stations when fading conditions existed. In these zones of weak reception, which more or less coincide with the so-called skip-distances, the received waves appear to be scattered in such a manner that direction finders fail to indicate any definite direction of origin or of propagation.

My observations were made on the S. Y. *Elettra* during a cruise which took place last August and September, when almost continuous observation was kept on the signals of eight beam stations situated at varying distances both great and small, and working on wavelengths of approximately 16, 26, and 32 meters.

It may well be that the amount of energy radiated by these stations along the path of the beams was sufficient to give signals on our receivers even at distances over which reception could not otherwise have been detected.

Before concluding this address I would like to put before you a few considerations in regard to what I believe is the relative value of short waves versus long waves for long-distance radio.

We all know that space is becoming seriously congested over a very considerable range of wavelengths, and as we have only one medium of transmission for us all, it may be well to figure out roughly the probable number of possible wavelengths or channels which can be used without mutual interference.

If we assume that long waves may be classed between 5000 and 30 000 meters, and short waves between 5 and 100 meters, then, by applying the basis of a rule proposed for the consideration of the International Radiotelegraph Conference at Washington, we find that 3700 wave-bands or channels will be practicable and permissible for the short waves, but only 90 for the long waves.

This, of course, is rather a conservative estimate of the number of channels, but should narrower wave bands be adopted the proportionate permissible number of short wave-bands would bear the same proportion to the possible number of long waves.

But, in addition to this very great advantage for the short waves, they have a further one due to the possibility of restricting a large proportion of their power to within a narrow angle and also to the screening effect of the receiving reflectors which, by very greatly reducing the angle of receptivity and, thereby, minimizing interference, tends still further to increase the number of separate services which can be worked by means of these waves.

We should also not lose sight of the fact that very high speeds of working appear to be possible only if short waves are employed, while, with the lower frequency of the long waves, speeds of the same order are quite unattainable.

I might, in other words, state that in regard to short waves there exists no theoretical reason why, with a frequency of 3 000 000, such as is the frequency of a 100-meter wave, the possible speed of working should not be 200 times greater than that attainable with a frequency of 15 000, which is that of the main transmitter of the high-power long-wave station at Rugby in England.

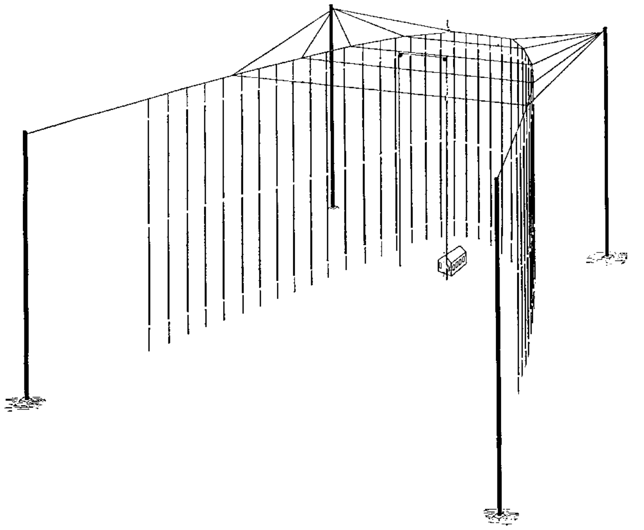

Fig. 11. Parabolic reflector with aerial at focus.

But long-wave stations, such as the one at Rugby, although utilizing a power of over 500 kilowatts cannot even communicate at low speed with Australia for the same daily average number of hours as is possible by means of an efficient beam station, although the latter be using only 20 kilowatts of electrical energy.

There is also an interesting and economic feature in regard to long-distance services by means of short waves compared with cables which should not be overlooked.

With cables, the capital and maintenance costs of the cable itself increase in simple and direct proportion with its length, but with short-wave radio it has been found that the capital cost of stations for communicating between England and Australia, over a distance of 10 000 miles, is materially less than the cost of stations for communicating with Canada over 2500 miles, i.e., over only a quarter of the distance, while, if anything, the service is better over the longer distance.

I have often been asked why it is that if these short waves are capable of covering the greatest distances without employing the beam system, I have always insisted on using it in all the stations my Company has established or is erecting for important long-distance services.

My reasons are that, as I have perhaps learned something in regard to the severe exigencies of present day commercial telegraphy, I have realized that in consequence of fading and atmospheric interferences the signals obtained from such nondirective stations are rarely strong enough for operating the recording instruments necessary for high speed commercial services required between important far-distant countries.

Doubts have also often been expressed by some experts as to whether or not the reflectors and directive aerials used at the various beam stations were in fact fulfilling any useful object at all.

The tests over long distances have already shown that the use of beam aerials and reflectors at both ends results in a signal strength which, from careful measurements, Mr. Franklin estimates to be on the average about 100 times greater than that obtainable with nondirectional transmitting and receiving aerials utilizing the same power.

Now, since the increase of strength of the received signals rises in proportion with the square foot of the power of the transmitter, it is easy to estimate that in order to obtain signals 100 times the strength it would be necessary to use 10 000 times the energy and, hence, as the power supplied to the anodes of the tubes is 20 kilowatts it would be necessary to use the impossible and absurd power of 200 000 kilowatts with the ordinary all-round radiating and receiving stations to give the same average strength of signals at the receiving end, if suitable reflectors were not employed.

During my recent cruise on the S. Y. *Elettra* I had numerous opportunities of testing the strength of many of the beam stations over both short and long distances, and although on this occasion I did not carry suitable measuring instruments, I am quite sure and satisfied that there is no possible doubt in regard to the very great increase in strength and reliability of the signals when these are received in the center or in the path of the beams as compared with those which can be received outside.

There exist, however, occasional periods, frequently coincident with fading conditions, when reflectors appear to be of no marked advantage. When such conditions prevail signals are seen not to arrive from any defined direction or angle but to be scattered to and from all directions, probably by the Kennelly-Heaviside layer, just as might occur from multiple reflection, or as in the case of diffused light.

This condition of scattering appears to prevail constantly at the so-called zones of skip-distances of each particular wavelength employed, and this fact may explain why certain observers in Germany and in America have found no trace of beam effect. If, as seems possible, their tests were made in the zone of skip-distances, the explanation appears clear.

These effects of the scattering of short electric waves have been carefully investigated by Mr. T. L. Eckersley of the Marconi Company who, I hope, will soon be able to publish a paper on the subject.

It is known that signals from the beam stations can be received at distant places far and wide and quite outside the angle of the beams, and it has also been suggested that this proves the inefficiency of the beam system.

It should, however, be remembered that a comparatively small amount of radiation escapes in all directions from the aerial and reflector system, and although this represents only a very small proportion or fraction of the energy contained in the beam, it is nevertheless capable of being detected, sometimes strongly, on sensitive receivers at very great distances in the same way as amateurs have shown us that the energy of a short-wave broadcasting transmitter, even when radiating only a few watts, can often be received and detected as far as the antipodes.

The same sort of effect occurs perhaps to a lesser degree even in the case of light when projected in a beam from a searchlight. Many of us may have noticed that it is usually quite easy to see plainly the beam of light projected by a

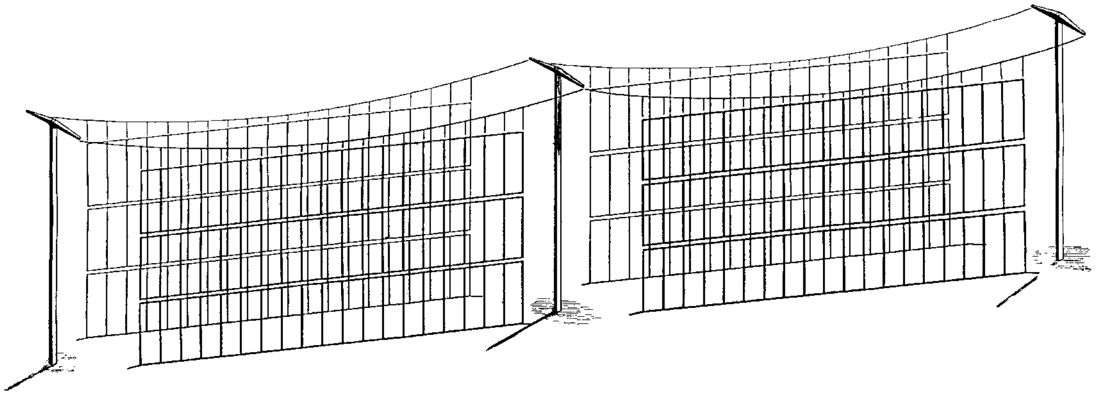

Fig. 12. Parallel flat aerial and reflector.

searchlight and its glare even when the beam is not directed toward the observer.

The signals which can be received outside the beams are, however, rarely strong enough to work high-speed recording instruments reliably, and as the messages which are sent in Morse code by the principal beam stations are normally transmitted at speeds approaching or exceeding one hundred words per minute, it is quite impossible to read them by ordinary aural or telephonic reception.

This affords a certain degree of secrecy not realizable by the older long-wave system.

Restriction of the angle of the beam and decrease of stray radiation outside of it appears, however, to be possible by increasing the dimensions of the reflectors in respect of the wavelength employed, and also by augmenting the number of wires in each grid. Further discoveries and the perfecting of design may also bring about this much-desired improvement.

Although the beam system is, in my opinion, still far from perfect, progress and improvement are continuous and the results already secured during many months of continuous working on a commercial basis across a variety of distances between so many different parts of the earth's surface have firmly convinced me that a good directional system is the system of the future for point-to-point radio communication over long distances throughout the world.

I have always felt that radio waves are far too valuable to be scattered and broadcast equally in all directions in a point-to-point service instead of being concentrated as much as possible on the station or group of stations with which it is desired to communicate.

The enormous increase in telegraphic speed is not the only advantage attached to the short wave-beam system: recent tests having fully demonstrated the adaptability of this system to radio telephony and also the ease with which it is possible to superimpose a commercial telephone channel upon high-speed telegraph services using the same system, as is now being done experimentally between Canada and England, thus obviating the cost of erecting separate stations for carrying on telephone communications.

The commercial advantages of such an important development of the application of short waves are very great and the opening of the first multiplex telephone and telegraph service will certainly constitute an important new departure in the history of long-distance radio communication.

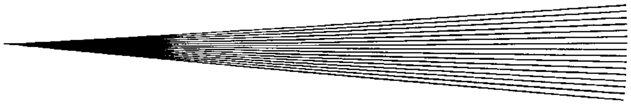

Fig. 13. The beam.

Much research work and the task of devising, designing, and testing the special arrangements and instruments used at the short-wave receiving stations have been successfully carried out by Mr. G. A. Mathieu of the Marconi Company.

Short waves are also beginning to show unhoped-for results in improving broadcasting and making it workable over great distances even during the hours of daylight. And directive methods, I feel confident, will soon be utilized for broadcasting by enabling programmes and speeches to be transmitted over large portions or sectors of America and to distant countries with much greater strength and freedom from interference than is possible with existing methods.

And, lastly, short waves cannot but enormously assist in rendering more practical the systems of picture and facsimile transmission including television, which are most likely to bring to an end the necessity for Morse code signal transmission on which is based telegraphy as we know it today.

In reviewing the progress recently made in the applications of short waves I may, perhaps, be forgiven if I say that it is with some considerable satisfaction and even pride that I am able to recall the fact, that when five years ago I last had the honor and pleasure of addressing you here, no practical use of short waves had yet been made and it was probably the first occasion on which the question of the urgent desirability of the study of short waves for practical radio purposes was publicly proposed and strongly recommended to the attention of experts.

I then stated that I considered we had perhaps got rather into a rut by confining all our researches and tests to long waves, because I felt that the study of short waves, although sadly neglected all through the history of radio, was still likely to develop in many unexpected directions and to open up new fields of profitable research.

The results obtained by amateurs by means of short waves do great credit to them, especially if we consider that most amateurs possess only limited facilities for experimental work. Their observations have frequently been of value in helping us to arrive at a better understanding of the very complex phenomena involved, but care should be exercised in accepting their observations, especially when they concern what I might term negative results.

Some short time ago I read a statement by an eminent English authority that, according to amateur observations, the daylight range of a 100-meter wave did not exceed 200 miles, and for a wave of 50 meters, 100 miles.

These distances were very far short of those ascertained by myself and my assistants, but it may very well be that some of the observers did not possess efficient receivers or that the location of their stations was not favorable to reception, or that they lacked operating experience.

I have always found that for reliable comparative observations and deductions in regard to transmission over different and varying distances there is nothing so good as a receiving station installed on a suitable steamship.

On a ship or yacht, one has the advantage of using the identical aerial system, the same receiving apparatus, and the same observers throughout, and at all distances, and this is, I believe, a most reliable way of testing the behavior of these waves, especially at what I might call intermediate distances.

Looking back at our old difficulties, of only a few years ago, the ease and perfection recently achieved by radio, especially in regard to broadcasting, appears little short of miraculous. It shows us what can be done by the combination of a great number of workers all intent on securing improved results. And how many, who began as amateurs, have contributed in one form or another to this progress and to this success?

We are yet, however, in my opinion a very long way from being able to utilize electric waves to anything like their full extent, but we are learning gradually how to use electric waves and how to utilize space, and thereby humanity has attained a new force, a new weapon which knows no frontiers, a new method for which space is no obstacle, a force destined to promote peace by enabling us to better fulfill what has always been essentially a human need: that of communicating with one another.