# Wireless World

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Radio Electronics Television

## 50 years of progress

# Wireless World

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HUGH S. POCOCK, M.I.E.E.

*Editor:*

F. L. DEVEREUX, B.Sc.

*Assistant Editor:*

H. W. BARNARD



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## *Fifty Years' Research in*

# RADIO WAVE PROPAGATION

By R. L. SMITH-ROSE,* C.B.E., D.Sc., F.C.G.I., F.I.R.E., M.I.E.E.

WHILE in 1911 great achievements had been attained in the practical developments of wireless telegraphy, there was little understanding of the manner in which the electromagnetic or radio waves involved travelled over the earth's surface; and particularly as to how it came about that these waves, which normally travel in straight lines, could bend round the spherical earth.

This was brought out very clearly in a lecture given by G. Marconi before the Royal Institution on 2nd June, 1911. The following extract is taken from the report of this lecture in the July, 1911, issue of the *Marconigraph*, a journal which was incorporated in the *Wireless World* less than two years later (April, 1913).

"Although we have—or believe we have—all the data necessary for the satisfactory production and reception of electric waves, we are yet far from possessing any very exact knowledge concerning the conditions governing the transmission of these waves through space—especially over what may be termed long distances. Although it is now easy to design, construct and operate stations capable of satisfactory commercial working over distances up to 2,500 miles, no clear explanation has yet been given of many absolutely authenticated facts concerning these waves."

Later on in the same lecture, Marconi said:

"Although the mathematical theory of electric wave propagation through space was worked out by Clerk Maxwell more than fifty years ago, and notwithstanding all the experimental evidence obtained in laboratories concerning these waves, yet so far we understand but incompletely the true fundamental principles concerning the manner of propagation of the waves on which wireless telegraph transmission is based."

Such statements, based on experimental measurements, aroused great interest since it had hitherto been considered that the electromagnetic waves involved travelled over the surface of the earth. The attenuation of the waves was less over sea than over land owing to the much greater electrical conductivity of salt water. W. Duddell and J. E. Taylor had shown in 1905 that for distances up to about 60 miles, the signal strength of radio waves was nearly inversely proportional to the distance between transmitter and receiver. But for distances beyond 100 or 200 miles, it was found by other investigators that signal strength decreased more rapidly; and L. W. Austin and L. Cohen obtained better agreement between calculated and measured signal strength by adding an exponential factor, involving both distance and wavelength, to the inverse distance relationship. Although this "Austin-Cohen formula" was used for several years by radio design engineers as a convenient practical guide, it was soon found to have serious limitations. The most important of these was the discovery that at distances greater than a few hundred miles, the strength of received signals varied from day to night: for the wavelengths and conditions then in use, the signal strength was usually greater, but more variable, by night than by day.

The first systematic discussion of these phenomena is also recorded in the issues of the *Marconigraph* for September to November, 1912, particularly by Drs. W. H. Eccles and J. A. Fleming, both of whom were closely associated with Marconi in his pioneer development of wireless communication. What was termed "The Effect of Daylight upon Radiotelegraphic Waves" became an active subject of discussion; and H. J. Round was the leading Marconi engineer who, with K. W. Tremellen, made many systematic measurements of the changes in signal strength over short and long distances due to the passage of the sunrise and sunset boundaries across the path. (See Fig. 1.)

At the 1912 Dundee meeting of the British Association Professor Fleming opened a discussion on the subject of "Unsolved Problems of Wireless Telegraphy," which was published in the *Marconigraph* for October, 1912. From the theoretical contributions made by Professors J. W. Nicholson and A. Somerfield, it became clear that diffraction alone could not account for the transmission of waves round the surface of the earth to the extent that had

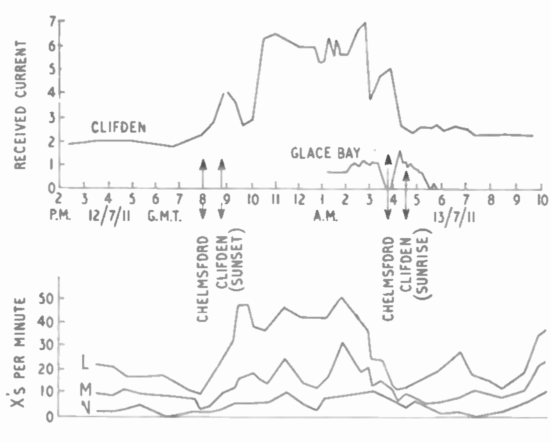


*Fig. 1. Measurements of strength of signals and atmospheric noise made at Chelmsford in July 1911. (a) The upper curves relate to the reception of signals from Clifden and Glace Bay. (b) Observations of the number of atmospherics per minute which produced peak voltages of 3(L), 6(M) and 12(N) respectively. Note the effect of day and night conditions on both signals and atmospherics.*

* President of the International Scientific Radio Union (U.R.S.I.).

already been demonstrated. Having regard to the long waves used, however, 6 km or more, and the difference in conductivity between land and sea, it was still necessary to consider the ground wave propagation phenomena up to moderate distances.

It was in the course of this discussion that the effect of sunlight on the propagation of radio waves was emphasized by Dr. Eccles; and he described in some detail his study of the possibilities of an ionized layer in the atmosphere acting as a reflector of radio waves as first suggested by Oliver Heaviside in 1900. With a further contribution from Professor A. E. Kennelly at the British Association discussion, the foundations were laid of an understanding of the characteristics of an ionospheric shell surrounding the earth and which, subject to variations in time and place due to the influence of solar radiation, could reflect upgoing radio waves back towards the earth's surface.

## International Collaboration

It was clear from this meeting (in 1912) that progress in investigating the complex phenomena involved could best be achieved by forming a committee or similar body comprising both theoretical and practical workers in the subject. It is therefore significant that in the following year a meeting was held in Brussels to discuss the formation of an international committee to organize and conduct scientific experiments in wireless telegraphy. A reunion was held in Brussels in April, 1914, at which a programme of scientific measurements was drawn up and discussed in some detail. This included observations of the variations in signal strength received in different directions and at various distances from the transmitter; and also simultaneous measurements of the strength of atmospheric disturbances in different places.

This body became the International Scientific Radio Union (U.R.S.I.), which held its first meeting in Brussels in 1922, and its XIIIth General Assembly† in London in September, 1960. During its nearly forty years of existence, the work of U.R.S.I. has covered a range of scientific subjects, such as standards of radio measurements and their application to wave propagation and radio noise, for the study of which on a world-wide scale, international co-operation is not only a great advantage, but indeed a necessity. In addition to pursuing scientific research on radio matters, U.R.S.I. has, for the past thirty years or more, collaborated with the International Radio Consultative Committee (C.C.I.R.) on many problems of mutual interest, particularly those concerned with the design and operation of long-distance communication circuits. It is natural to find that this co-operation is actively continuing in connection with the more recent problems of radio astronomy and communication to and from vehicles in space.

## The Ionosphere and Round-the-world Transmission

It was not until 1925 that the first experiments which demonstrated the existence of the Kennelly-Heaviside layer were made by Sir Edward Appleton and his co-workers using the Bournemouth transmitter of the B.B.C. By changing the frequency of this station, the strength of the received signal was found to vary, indicating an interference pattern such as would be produced by two sets of arriving waves, one travelling along the ground and another coming down after reflection at the ionized layer. (See Fig. 2 (a) and (b).) Confirmatory evidence was found by comparing the signal variations obtained when receiving on a loop and vertical aerial. An alternative method was used by R. L. Smith-Rose and R. H. Barfield, who compared the strength of signal from a transmitting station received simultaneously on a loop and vertical aerial. All these experiments indicated that the radio waves used—about 300m in wavelength—were reflected from an ionized layer at a height of about 100 km. Almost concurrently with this work G. Breit and M. A. Tuve used a pulse technique to measure directly the time interval between the arrival of the pulses travelling along the ground and those which arrived later after travelling up to the ionized layer and down to the receiving station. (See Fig. 2 (c).) A year or two later, by using shorter wavelengths, Appleton and his co-workers showed that at certain times the radio waves could penetrate the first reflecting (or E) region and be reflected from an upper region, termed F, at a height of some 400 or 500 km.

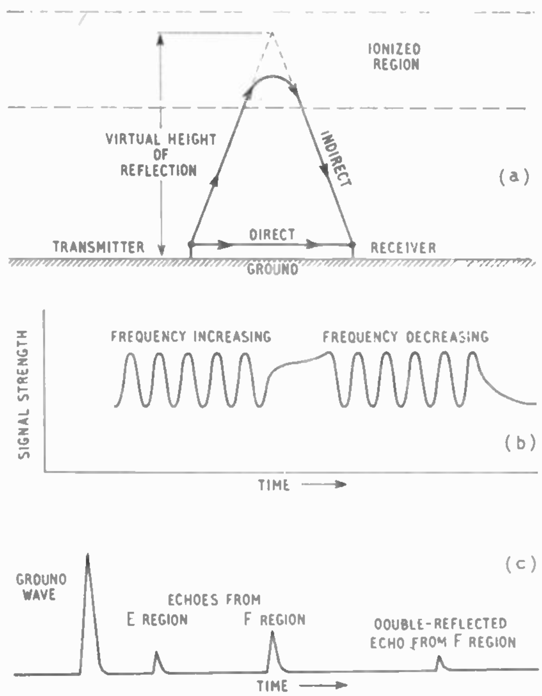


*Fig. 2. (a) Paths of direct and indirect waves from transmitter to receiver; and the measured—or virtual-height of reflection of the indirect wave. (b) Interference fringes in received signal due to ground and ionospheric waves, as the frequency of the transmitter is varied over a small range. The ratio of the number of signal maxima to the change of frequency gives the difference in time of arrival of the two signals, and so the height of reflection of the indirect wave. (c) Echoes of transmitted pulses after reflection from the lower (E) and upper (F) ionized regions: and also of an echo of a pulse which has been twice reflected from F with an intermediate reflection at the ground.*

† A brief account of this meeting was given in *Wireless World*, January 1961, p. 10.

These pioneer experiments and discoveries provided, first the complete explanation of the manner in which radio waves can travel right round the earth by successive reflections between the earth and the upper atmosphere; and, secondly, the basis of the subsequent exploration of the physical characteristics of our upper atmosphere which has been in progress for the past thirty years or more. Ionospheric observatories have come into operation for measuring the height and density of ionization of the various reflecting regions, and the manner in which these change from day to night and from summer to winter. The installation of such observatories has gradually spread throughout the world, to over 250 which were in operation on a regular and systematic basis during the International Geophysical Year of 1957-58.

As a result of the international collaboration obtained under the auspices of U.R.S.I. observations made in different parts of the world are freely exchanged, so that national laboratories can prepare charts showing the state of ionization in the upper atmosphere all over the world. Based on data accumulated in this way, over one or more solar cycles of 11 years duration, accurate forecasts can now be made of the ionospheric conditions to be expected up to six months in advance.

Concurrently with this observatory work on conditions at vertical incidence, continuous studies have been made on the transmission of radio waves over oblique incidence paths at distances from a few hundred up to several thousand miles between sending and receiving stations. In this way, a detailed and fairly accurate knowledge has become available for use in the design and operation of long-distance radio communication services throughout the world. The frequencies or wavelengths to be used for such services can be selected in advance according to the time and geographical location of operation, and systematic planning can take place to deal with the diurnal fluctuations in ionospheric conditions as well as with the longer-term variations which follow the solar cycle.

## Radar Technique and Back-scatter

It is well known that the use of pulse transmission and receiving technique formed the basis of the development of radar for detecting and locating ships, aircraft and geographical features. It seemed only just, therefore, that research workers concerned with the exploration of the ionosphere should take advantage of advanced and powerful radar techniques for their continued investigations. Following earlier work by T. L. Eckersley on the scattering —as distinct from reflection—of radio waves from ionospheric clouds or regions, E. D. R. Shearman used a high-power radar transmitter to direct a beam of waves horizontally. The waves after reflection from the ionosphere reached the earth's surface at some one or two thousand miles from the transmitter. Some of the energy of the waves was scattered backwards, and after a second reflection at the ionosphere was detected at a receiver alongside or incorporated with the transmitter. From a measurement of the time taken for the pulses of radio waves to travel to and from the sending station, the path of the waves was determined. Furthermore observations made on various frequencies soon showed the characteristics of the ionosphere at the distant reflecting region. By suitably rotating the aerial system, the beam of waves was made to scan the horizon, and in this way the conditions in the ionosphere all round the observing station could be explored at ranges up to 7,000 miles or so. This technique has proved to be a powerful tool not only for the scientist investigating the ionosphere all round him, but it also enables the radio operator of a long-distance circuit to determine from time to time the best and most suitable frequencies to use in the prevailing circumstances.

## Propagation at V.H.F.

In general, radio communication services which make use of ionospheric propagation are confined to frequencies below 30 Mc/s (wavelengths above 10 metres): although it has long been known that under appropriate conditions the density of ionization in the ionosphere is at times sufficient to support the transmission of radio waves within the band 30 to 50 Mc/s. But experience has shown that this type of transmission is comparatively rare and inefficient with normal transmitter powers and receiver sensitivities. To obtain anything approaching a regular service, it is necessary to use the scattering of the waves at the ionosphere which, on account of the weakness of the resulting signals, entails the use of very high power and concentrated beams of radiation. This technique is, however, used in certain "ionospheric scatter" services where the utmost reliability is necessary at all times, irrespective of economy and efficiency.

The main use of the v.h.f. band between 30 and 300 Mc/s (wavelengths 1 to 10 m) is, however, for the localized services involved in broadcasting, television, police and private mobile services, and certain types of beacon and navigational aids mainly perhaps, for aircraft services. These services as used today, are based on the knowledge obtained in research on the propagation of such waves over the past thirty years or so. The subject here is broadly divisible into two parts. First, a study of the electrical characteristics and the physical features of the earth's surface, which mainly determine the transmission of the waves to short distances broadly within the horizon as seen from the sending aerial. Secondly, and particularly at the longer distances beyond the horizon, the strength of the waves arriving at the receiver may be affected to a varying extent by the bending of the waves due to the refractive index gradient in the atmosphere. This refractive index gradient is determined by the temperature, pressure, and more especially, the humidity of the atmosphere, and so the extent to which the waves are bent is very dependent on the weather conditions prevailing over the transmission path.

But considering the shorter-range phenomena first, in order to extend the horizon and so the service of a transmitting station, it is usual to elevate the aerial of the latter as much as possible. It then becomes clear that there are two paths by which the waves can travel towards the receiver. One of these is directly through the air from transmitting to receiving aerial: while the other path involves reflection from the ground, the inverse of reflection from the upper atmosphere. The resulting signal at the receiver is the combination of these two sets of waves, which are usually out-of-phase in practice, and result in the signal strength being inversely proportional to the square of the distance between sending and receiving stations. There are, of course, wide variations in practice from this simple law, mainly due to the effect of obstacles such as hills and buildings in the path of the ground reflected waves.

Next, as already suggested, the direct waves which travel through the air may be subject to bending which may result in their being propagated appreciably beyond the horizon. As a result the "service area" of such a transmitting station is increased beyond the limits of the optical horizon, albeit the extended range is variable and dependent upon the prevailing atmospheric conditions. For practical purposes, in such cases as broadcasting and television services, measurements are made over long periods of time and in various parts of the world to obtain sufficient data to express the results on a statistical basis. An example of the application of this type of study is shown in Fig. 3 which is reproduced from a recommendation of the C.C.I.R. in 1959, setting out the field strengths likely to be received at various distances beyond the horizon for typical proportions of the time of observation. Such information is of direct importance to designers of broadcasting services, and assists them to determine the minimum separation in distance necessary between stations operating in the same frequency channel to secure comparative freedom from any specified degree of mutual interference.

## Future Research in Radio Wave Propagation

A general view of the trend of future scientific research in this subject of radio wave propagation can be obtained from the conclusions and recommendations of the various Commissions of U.R.S.I. concerned with this subject. In the first place interest in the propagation of waves through the lower atmosphere is not confined to those concerned with communications. As Commission I indicated, the measurement of standards of frequency and time has become so precise that it is very important to know what changes in phase of both low and very low frequency waves occur over various transmission paths. Furthermore, since both light and radio waves are used in geodetic surveying, it is important to standardize the formulæ used for calculating the refractive index of the air at the working frequencies.

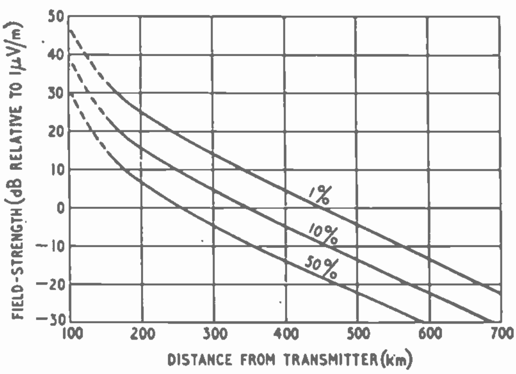


*Fig. 3. Frequency range: 40 to 600Mc/s. Values of field-strength for 50% of locations for 1kW radiated power by a half-wave dipole with vertical or horizontal polarization exceeded for 1%, 10%, and 50% of the time. (The dashed portions of the curves are less reliable than the portions shown in full lines.)*

Commission II, dealing with propagation through the troposphere, pointed out that, while further quantitative studies were required to elucidate the statistical facts of propagation beyond the horizon, it was also important to investigate the fine structure of irregularities in the atmosphere. The latter become of increasing importance in connection with the absorption and scattering in the atmosphere at centimetre and millimetre wavelengths. Also, since many of the frequencies likely to be used in space research are susceptible to tropospheric influences, the importance of the effects of these should be examined.

With regard to the propagation of waves through the ionosphere, a subject concern to Commission III, the great co-operative work carried out during the International Geophysical Year (1957-58) has been described in previous publications.§ At last year's General Assembly of U.R.S.I. it was noted that several scientific unions, including the International Committee on Geophysics, were organizing a Sunspot Minimum Programme to be conducted during 1964-65 as a companion enterprise to the I.G.Y. which, as is well known, took place during a period of maximum solar activity. The results of this international effort should do much to elucidate some of the outstanding features in our knowledge of the ionosphere, which by 1965 will have been the subject of study by radio scientists for over forty years. By this date also, it may be anticipated that the use of rockets and artificial earth satellites will also have appreciably added to our knowledge of the upper reaches of the ionosphere, which it has so far been difficult to explore by radio waves sent up from ground stations.

Fifty years ago, Marconi engineers and others were recording the number of atmospherics—or X's as they were then termed—which produced a certain voltage across the receiver terminals (see *Fig.* 1). This study of "Radio Noise of Terrestrial Origin"—to use the present title of Commission IV of U.R.S.I.—has continued ever since on a continually increasing scale all over the world. The number and variety of the various types of noise which produce an audible or detectable response on modern sensitive receivers is now so great that it was decided at the recent General Assembly of U.R.S.I. to draw up an agreed terminology of the subject. Terrestrial Noise comprises those natural electromagnetic disturbances which originate in the earth's atmosphere, and there appear to be four recognizable classes of such noise:

(i) Atmospheric noise which originates in natural electrical discharges below the ionosphere, and which travels to the receiver by the normal paths of propagation between the earth and the lower boundary of the ionosphere.

(ii) Ionospheric noise which originates in the ionosphere and is usually associated with magnetic disturbances.

(iii) Whistlers which are a form of terrestrial noise, originating in electrical discharges in the lower atmosphere, and which are propagated through the ionosphere along dispersive paths. The whistler type of noise when heard at a receiver is characterized by one or more components of the nature of gliding tones, which descend in frequency through the audible range in a period ranging from a fraction of a second to several seconds.

§ See, for example, *Wireless World*, February 1960, pp. 52-58.

(iv) Finally, composite noises are recognized as having the combined characteristics of whistlers and ionospheric noise. Such "interactions," as they are termed, may be initiated by lightning discharges and are often associated with magnetic disturbances.

The continued study of this subject is helping to elucidate some outstanding problems on the nature of the earth's magnetism as well as on the physical characteristics of the upper atmosphere.

In this article, an attempt has been made to describe briefly some of the advances made, during the past fifty years, in the study of the propagation of radio waves around our earth and also through its atmosphere.

Much has been learnt and understood about the physical processes and conditions involved: much more remains to be discovered; and interest in future research will be greatly quickened by the possibilities of the new tools available to the radio scientist in the form of rockets and artificial satellites and the associated measuring techniques and instruments.

# INDUSTRIAL GROUPS—VI

*The Victorian origin of the wireless industry in this country is apparent from this photograph taken in the Marconi works over 60 years ago.*

THE history of the **Marconi** company, and therefore that of the radio industry, started with the formation on July 20th 1897 of the Wireless Telegraph and Signal Company (soon afterwards renamed Marconi's Wireless Telegraph Company). Two years later the company established its first factory in Chelmsford, Essex. Since 1946 Marconi's W/T Company, together with its subsidiaries and associated companies has been part of the **English Electric Group**.

As will be seen from the following list the group,

English Electric Co. Ltd.
D. Napier & Son and its subsidiaries
Marconi's Wireless Telegraph Co and its overseas subsidiaries
Marconi Instruments Ltd.
Marconi International Code Co.
Marconi International Marine Communication Co. and subsidiaries
Marconi Radio Sounding Device Co.
Marconi Television Co.
Radio Communication Co.
Scanners
Vulcan Foundry
Robert Stephenson & Hawthorns Ltd.
English Electric Valve Co.
English Electric Export and Trading Co
Canadian Marconi Co.
John Inglis Co., Toronto.
English Electric Canada
English Electric Company of South Africa (Pty.) Ltd.
English Electric Company (Central Africa) Ltd.
English Electric de Venezuela
English Electric Company of India (Pty.) Ltd.
English Electric Company of Australia Pty. Ltd.
English Electric Company of New Zealand Ltd.
English Electric Espanola
English Electrica de Portugal
English Electric Marconi Argentina
Associated Transistors Ltd.
British Aircraft Corporation and its subsidiaries
English Electric, Babcock & Wilcox and Taylor Woodrow Atomic Power Construction Co.
Kingsway Housing Association
Power Traction Finance Co.

of which Lord Nelson of Stafford is chairman, now comprises over 30 allied and associated companies. It employs 84,000 people in its 24 principal works in this country and abroad. The group's interests are too diverse to be covered adequately in a short survey, but they range from aviation to atomic power plant, electrical generation to electric cookers, traction equipment to transistors, marine engines to marine radio, transmitters to turbines, and klystrons to computers. Its radio and electronics interests are not, however, concentrated in the Marconi section of the group, for the English Electric Company itself has been in the forefront of the development of electronic computers and, jointly with the Automatic Telephone and Electric Company, operates Associated Transistors Ltd., manufacturers of semiconductors. Also the English Electric Valve Company produces the "glassware" which is the very heart of the transmitters, radars, television cameras, etc., produced by Marconi's.

The English Electric group profit for 1960 of £3,142,580 (after providing nearly £3M for taxation) is slightly above the previous year's figure. The group has an issued share capital of nearly £33M, fixed assets of nearly £44M and current assets of £48M.

## Reactance Calculator

A SLIDE-RULE Calculator measuring $8\frac{3}{4} \times 3\frac{1}{2}$in providing a simplified means of calculating resonance frequency of tuned circuits, reactance of inductors and capacitors, Q of coils and dissipation factor, all over a wide range of values, has been introduced by Shure Brothers Inc. of Evanston, Illinois, U.S.A. It is, however, obtainable in the U.K. from J. W. Maunder, 22 Orchard Street, London, W.1, at the modest price of 12s 6d.