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WORLD WIDE COMMUNICATIONS WITH SHORT WIRELESS WAVES*

By T. L. Eckersley, B.A., B.Sc. and K. W. Tremellen.

In this article the conditions which control short wave long distance communication are discussed, certain problems of short wave propagation are experimentally attacked, and the method of applying the knowledge so obtained in projecting new services is given.

For convenience the article is divided into three parts :—

(1) *A summary of modern transmission theory.*
(2) *Experimental results obtained from a 12-months' interception of short wave wireless signals.*
(3) *Practical application of the results obtained from the above to the projection of new services.*

It should be noted that the subject matter on pp. 15, 16 and 17 is an addition to the original article.

Modern Transmission Theory.

In modern transmission theory it is recognised that the upper ionised region of the atmosphere known as the Heaviside layer, plays a predominant part.

Radio research has given us a comprehensive, if not yet very accurate, picture of the nature of this layer. The region is conducting on account of its ionised state. The ionisation in the daytime is almost certainly produced by the sun's ultra violet radiation, and extends down to heights of approximately 80 km. above the earth's surface, but at night time the ions in the lower parts of the layer rapidly recombine and leave the higher regions ionised down to heights of 100 to 130 km.

The ionic density N according to the most recent experiments, rises to a maximum of about $N=10^5$ at 100 km. height, dies away, and then increases again to values rather greater than this at 240 km. above which height very little is known.

The mean time between the successive collisions of an electron with the molecules of the air is a critical factor in determining the behaviour of the waves in the medium,

* This article is a summary of the paper read before the "World Engineering Congress" held at Tokio in October, 1929.

for if the electrons can move freely and make many oscillations in the time between collisions, the behaviour is determined by Eccles theory of ionic refraction, and obviously applies to all short wave transmissions of frequencies greater than 3 by 10^6 (or wavelengths less than 100 m.).

The conditioning factors at any point in the layer are (1) the ionic density N; (2) the gradient of the density $\frac{\delta N}{\delta h}$ and (3) the collision frequency $\frac{1}{\tau}$.

The essential conditions for long distance transmission are, firstly that the rays shall be sufficiently bent round the curvature of the earth, and secondly, that the attenuation along the path shall be sufficiently small.

The failure of any signal to "stay the course" can be attributed to the failure to satisfy one or other of these conditions.

With regard to the ray bending, the relations which follow from the theory may be expressed thus :—

Let N maximum be the maximum density which occurs at a height h, then the shortest wave that will be sufficiently bent to come down to earth is given by

$$\lambda^2_{\min} \cdot \frac{Ne^2}{\pi m} = \frac{2h}{R} \text{ approx.}$$

$$\text{or} \quad \lambda^2_{\min} = \frac{2h}{R} \frac{\pi m}{Ne^2}$$

Shorter waves than this escape from the earth and travel into outer space.

The attenuation constant at any point of the layer where the density is N, the collision frequency $\frac{1}{\tau}$, e and m the charge and mass of an electron, and c the velocity of light, is $\frac{Ne^2\lambda^2}{\pi mc\tau}$ and is jointly proportional to the ionic density N, the square of the wavelength λ^2, and the collision frequency $\frac{1}{\tau}$.

It will be observed that if two signals of wavelength λ_1 and λ_2 follow the same path, the relative attenuation of the two will be proportional to the squares of their wavelengths.

If we could specify the values of the quantities N, $\frac{1}{\tau}$, and $\frac{\delta N}{\delta h}$ at every point on the path of a ray between the transmitter and receiver we should have the data necessary for computing the signal strength received per kw. radiated.

These quantities, which measure the state of ionisation of the upper layer above a given point on the earth's surface, depend essentially on the local time at

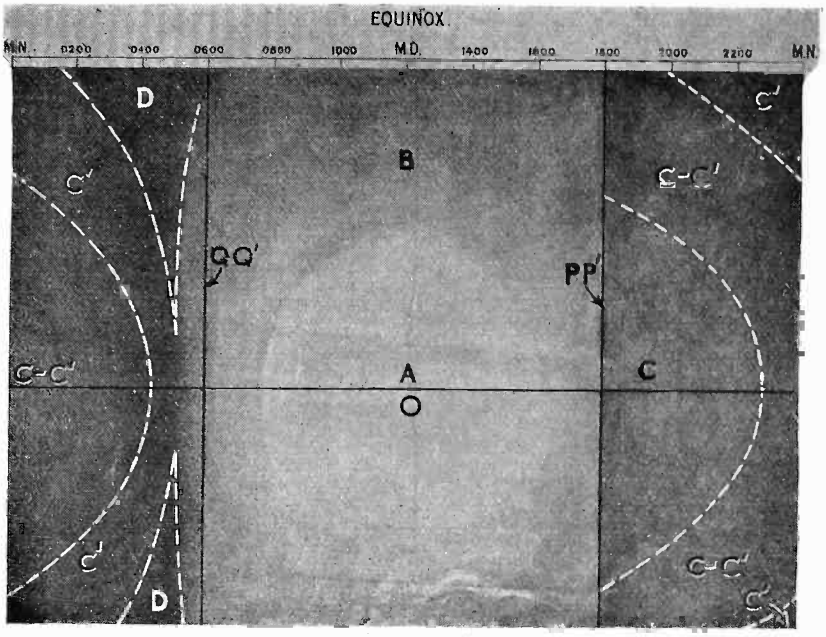

EQUINOX.
M.N.
0200
0400
0600
0800
1000
M.D.
1400
1600
1800
2000
2200
M.N.
D
B
C'
C-C'
QQ'
PP'
A
O
C

FIG. 1.

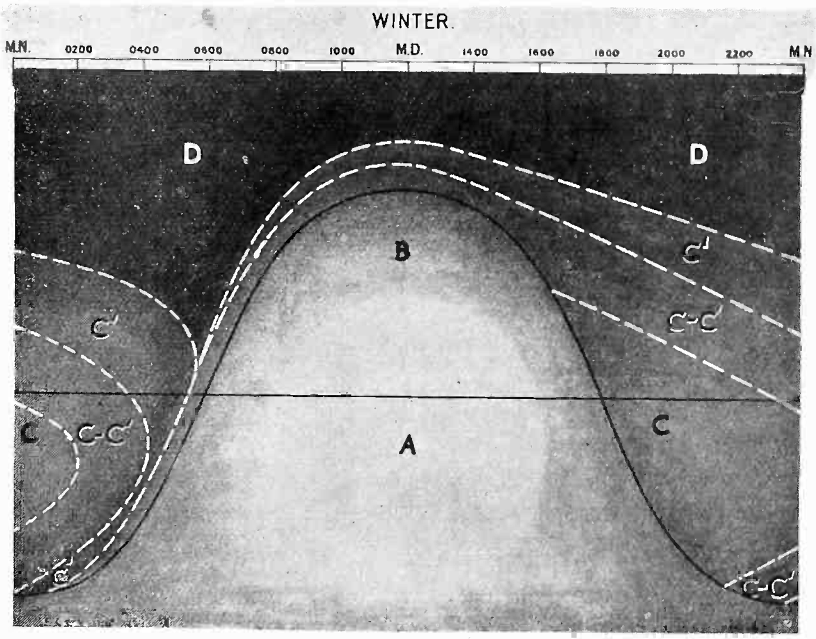

WINTER.
M.N.
0200
0400
0600
0800
1000
M.D.
1400
1600
1800
2000
2200
M.N
D
B
C'
C-C'
A
C

FIG. 2.

that point, for the ionisation, which at any rate in the lower layers is produced by the sun's ultra violet radiation, depends on the sun's position angle and therefore on the local time.

The transmission between any two points on the earth's surface will have a regular diurnal cycle as the earth revolves below the layer, the characteristics of which remain constant relative to the sun's position. Such diurnal cycles have, of course, been observed on the transmission characteristics of all sufficiently distant stations.

For the purpose of specifying the condition in the upper atmosphere we have to prepare charts of it giving these quantities relative to the sun's zenithal position.*

Strictly speaking a triply infinite series is required to give these three quantities at every level in the Heaviside layer. This being obviously impracticable, we have to be content with a single chart which may be interpreted to give the condition along the route of any path with sufficient definiteness to allow predictions to be made.

By marking off the regions in various grades, we can obtain an estimate of the total attenuation along any route. In compiling the chart the continuous series of observations has been most useful and we have brought to it all our knowledge obtained from all sources, whatever they may be.

The construction of the chart may be explained with reference to the theory as follows :—

To represent the whole Heaviside layer or conducting layer 80 to 200 km. above the earth's surface on a flat chart, a Mercator's projection is used. The simplest representative case is that drawn for the equinoxes. In this case the sunset and sunrise lines (the division between light and darkness) are meridians, and are represented PP and QQ (Fig. 1). The region between these two is illuminated by the sun's rays and outside them is in darkness. Figs. 2 and 3 give similar charts drawn for mid-winter and mid-summer respectively in our hemisphere.

Use of Shadow Charts and Map.

The conditions of light and dark on any route may be obtained at any season and at any time by placing the chart (which in practice should be printed on transparent paper so that the map underneath can be easily seen) corresponding to the season required over the map, with the line marked Equator on the chart coinciding with the Equator on the map and with the time as shown in G.M.T. at the top of the chart, against the arrow drawn through the Meridian of Greenwich. Thus taking the Winter chart Fig. 4 as an example, it will be seen that at midday G.M.T. the route to Capetown is almost entirely in intense daylight. The route to India is entirely in twilight, and of the two routes

* Note that the conditions at any point in the upper atmosphere only depend on the position of this point relative to O, and are independent of the rotation of the earth below the layer.

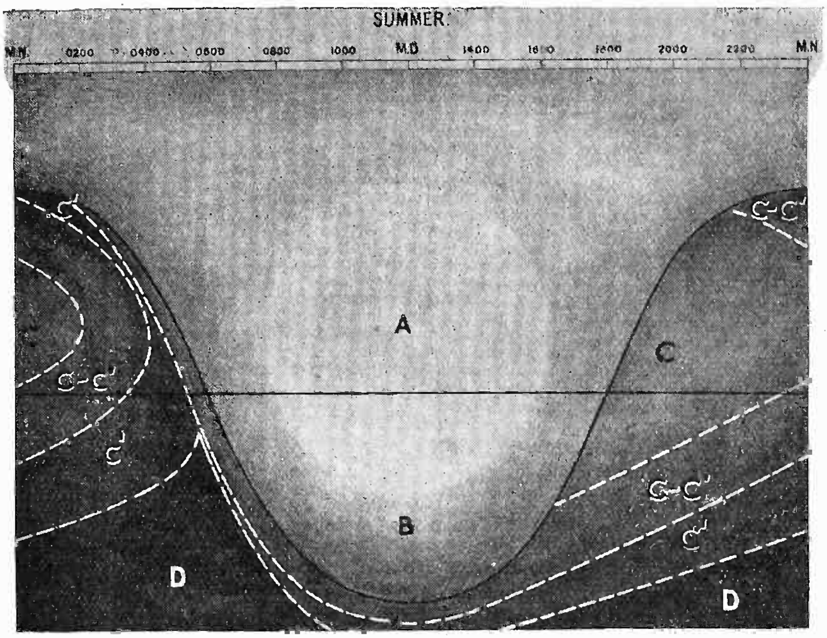

SUMMER
M.N.
0200
0400
0600
0800
1000
M.D
1400
1800
2000
2200
M.N
A
B
C
D
D

Fig. 3.

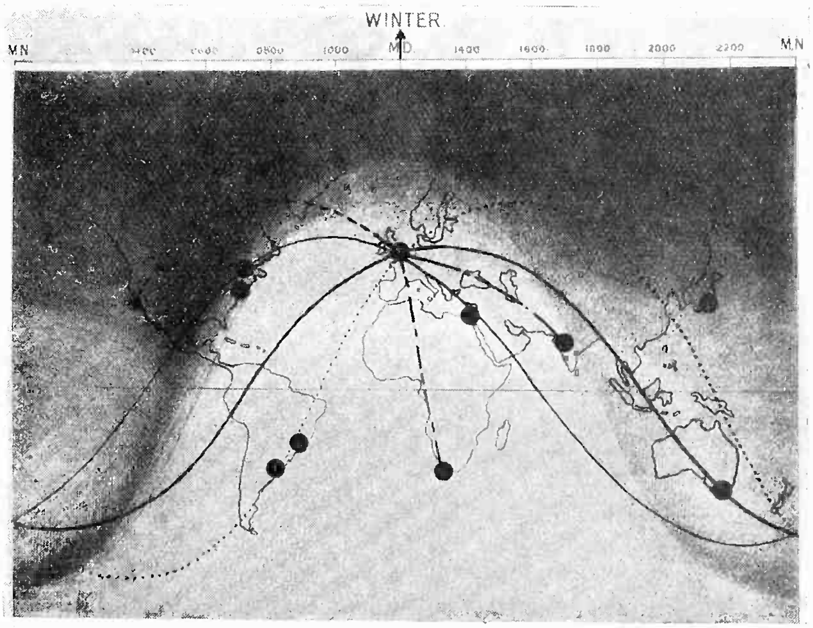

WINTER
M.N
0800
1000
M.D
1400
1600
1800
2000
2200
M.N

Fig. 4.

to Australia, that via India traverses a mixture of twilight and early or tropical night, whilst that via the Pacific passes through twilight bordering on the intense daylight, followed by twilight near the shadow band, then a small portion only of late night darkness (as it is Summer in the Southern Hemisphere) and finally a small portion of Summer darkness. An illustration of the chart and map combined is shown in Fig. 4.

In the latter part of this paper examples will be given of the use of these charts in explaining the vagaries of short wave communications.

Direction Finding and Scattering.

It has been tacitly assumed that except in the case of scattering the rays follow the great circle paths on the globe and the development and use of the short wave direction finding apparatus have enabled us to state with certainty that this is actually so for long distance transmissions in all but exceptional cases.

A new factor scattering, discovered by the direction finder is not of major importance in determining signal strengths except within the skip distances, where the illumination consists wholly of scattered radiation. It has, however, a very profound effect in the blurring of signals, and sets a limit in many cases to high speed transmission. Where signals are largely scattered they will arrive at the receiver by devious routes, the signals by the longer paths arriving later than those by the direct path. This results in a lengthening and blurring of the Morse marks. Signal retardations due to scattering of 0·01 sec. and more are known, and will completely blur high speed morse.

The most direct proof of scattering was obtained from the behaviour of the local English Beam Stations observed at our receiving station at Chelmsford, near London. It was noticed that these stations gave quite well defined bearings which were not the true bearings. Thus, for instance, the Bodmin (W. England) beam sending to South Africa gave approximately the bearing of Capetown. Similarly, Bodmin sending to Montreal gave approximately the Montreal bearing, etc. This peculiarity can be best explained by the analogy of a searchlight. A closed in searchlight will reveal itself chiefly by the light scattered from the region where the beam illuminates the clouds. In the same way the source of energy from the beams is the point where they enter the scattering layer.

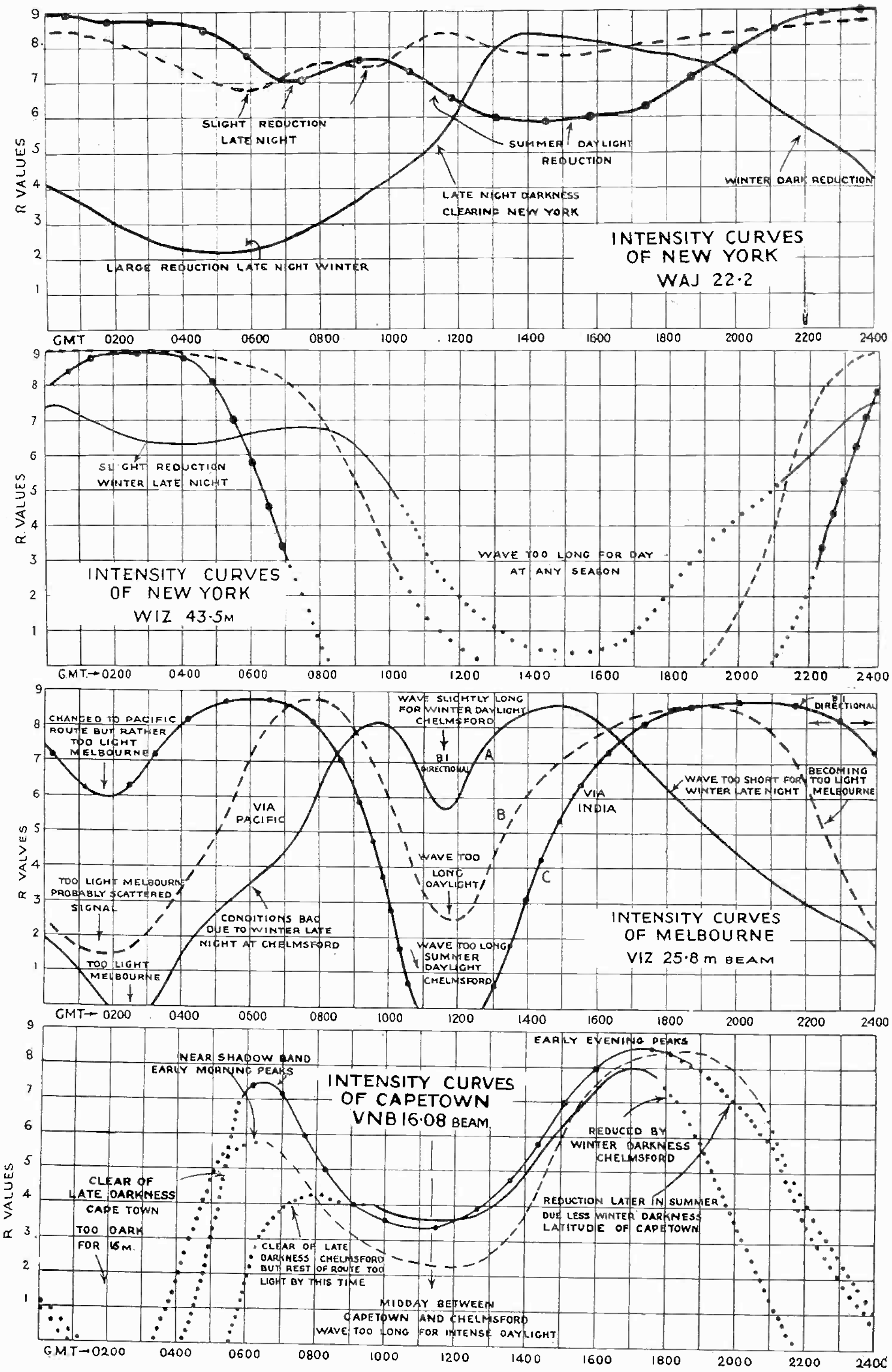
Magnetic storms play havoc with short wave communication.

An extended series of regular observations is of the greatest value in determining the statistical relation between short wave fades and magnetic storms. Such a relation undoubtedly exists and is borne out by observations.

The services appear to be affected in a degree proportional to the nearness of their paths to the magnetic poles, where magnetic storm effects are most intense, but this gives an added reason for supposing that there is a physical relation as well as statistical relation between magnetic storms and short wave fades.

Experimental Results.

Continuous interception of short wave wireless signals between 15 and 50 metres



FIGS. 5, 6, 7 & 8.

——— WINTER. —•—•— SUMMER. – – – – EQUINOX. •••••••••• CALCULATED.

was carried out from October, 1927, to October, 1928, using a simple type of receiver.

The strength of signals was estimated by ear, and graded in strength of from R1 to R9. At the end of each month curves were prepared for each station embodying all the signal strength values obtained during the month. The curves then represented the average values of signals from that station for the month.

The curves, Figs. 5 to 8 inclusive, have been chosen to illustrate typical effects of light, dark and seasons. The reasons for the various forms taken by the curves are given on the curves, and can be made clearer by the use of the map and shadow charts.

In addition to the observations on signal strength, direction finding apparatus was used from time to time to study the directional properties of signals received from long distance and nearby stations.

Conclusions from Twelve months observations.

Signal intensity apart from abnormal conditions is dependent on *distance*, and *light and dark conditions*, the latter being dependent on latitude and seasons. Land and sea effects are probably only noticeable on the direct surface ray which is only received up to comparatively short distances.

As regards distance, the "skip" effect either partially or entirely eliminates the reflected main ray signal over a distance depending on the wavelength and the light and dark conditions existing at the time. When signals are received in the "skip," observations by means of the direction finder show that they are either scattered uniformly from all parts, or more or less definitely from a particular source or sources at which the scattering conditions are best at the time. In cases where communication is confined to the daylight area in which the sun's altitude is more than about 30 degrees, the distance appears to vary inversely as the square of the wavelength. The table gives the approximate distances at which signals ceased to be audible on various wavelengths on the simple receiver used during the tests. These distances apply to the daylight area just mentioned.

TABLE I.

APPROXIMATE DISTANCES IN MILES AT WHICH SIGNALS CEASE TO BE AUDIBLE.
INTENSE DAYLIGHT ROUTE. FOR APPROXIMATELY 10 KW.

Wavelength in metres.	Distance in miles.
15	12,000
20	7,000
25	4,500
30	3,000
40	1,500
50	900

As regards light and dark the case becomes more complex. It should be pointed out that previous to the commencement of the year's interception, day and night conditions had been assumed to be either light or dark or half light half dark. It soon became obvious, however, that to account for various effects noticed in the variation of signal intensity, it was necessary to divide the daylight and the darkness into grades depending on the altitude of the sun in the case of daylight, and on the latitude and the time after sunset in the case of darkness.

In order to illustrate this more clearly, reference should be made to the Shadow Charts, Figs. 1, 2 and 3. Taking Fig. 1 for the Equinoxes as the simplest case, the light and dark conditions which exist at the Greenwich times shown at the top of the chart are approximately shown in six grades, A,B,C, c-C′,C′, and D. The horizontal line represents the Equator, the vertical line QQ′ sunset, and the vertical line PP′ sunrise.

The gradation of the shaded areas has been obtained from a study of the behaviour of signals at various times and on various wavelengths.

For simplicity only six grades of light and dark have been taken, but it should be understood that the intermediate grades exist especially in the night period. The border line of grade A gives approximately a line on which the sun's altitude is about 30 degrees. This grade again for simplicity is shown as a single grade but the effect of the sun's rays is more marked at the centre than at the edge of this circle. The gradation of the light and dark thus obtained from the year's observations is also shown in Figs. 2 and 3 for winter and summer conditions in the Northern Hemisphere, and it will be seen that in winter due to the long nights, grade D predominates. The gradation is really an indication of the ionic density existing at the time, the darker the grade the less the density, and from signal strength observations, the minimum density is reached about an hour before the sunrise. For this reason grade D ends about an hour before the sunrise line on the charts.

It should be pointed out that although the daylight grade A is shown for simplicity as a circle, due to the Mercator projection used, lines of equal altitude of the sun's rays are only true circles near the centre of grade A. The true form of grade A as shown at the equinoxes is an ellipse with major axis North and South. In the summer months in the Northern or Southern Hemisphere this ellipse opens out somewhat to the East and West in high latitudes extending into the polar regions. Due to the fact that very few communication routes pass through the polar regions, our observations on the light and dark conditions existing there are limited.

The effect of light and dark may be briefly stated as follows :—

GRADE A.—*Intense Daylight.*

On the longer waves the attenuation is great, and waves below about 18 m. are necessary for long distance communication through this grade. Even on the shorter waves about 15 m. attenuation is appreciable when the route is of great length and traverses the centre of grade A.

GRADE B.—*Twilight.*

The attenuation on all waves is reduced, particularly on the shorter waves where it becomes extremely small.

GRADE C.—*Summer and Tropical darkness, excepting late night.*

The attenuation on all waves during the early portion of grade C is extremely small, but during the later portion, in grades CC′ and C′, the short waves below about 20 m. are reduced although the waves above about 20 m. are not affected to the same extent.

GRADE D.—*Winter darkness existing during the whole night in polar latitudes and all but the first few hours of the night in middle latitudes in winter.*

When the ray path traverses this type of darkness, the attenuation on wavelengths of 50 to 100 metres is small, but all signals below about 50 m. are reduced in strength. The reduction is slight above 40 m., but becomes considerable as the wavelength is reduced, until below about 24 m., signals are frequently inaudible, and no signal is received below wavelengths of about 18 m. The reason for the reduction of short wave signals in grade D, and in the intermediate grades between grade C and grade D is probably due to a lack of sufficient bending of the rays.

In this connection, it should be mentioned that the effects of darkness in reducing the signal strength of the shorter waves applies chiefly to any communications taking place over routes entirely in darkness. There appears to be no doubt from observations that in those cases where the transmitting and receiving stations are in daylight or twilight and the late or winter darkness exists only en route the effect of the latter is greatly minimised. In other words, if the bending is sufficient at both transmitting and receiving stations, signals are enabled to traverse the darker grades. The cases in which such conditions can occur are rather limited, but a good example is found when the transmitting station is near the border of grade A and the receiving station is at a point opposite to it also on or near the border.

In such a case, signals are frequently partially or entirely received by the longer dark route in spite of the fact that considerable distances on this dark route are through winter or late night which would reduce or possibly render inaudible, signals between two stations situated actually in that darkness. In the case just mentioned, echo signals would be heard on wavelengths short enough to permit a signal to traverse the highly attenuating shorter portions of the route across grade A, and providing the wavelength was not too short for the long dark route at the same time. *Echo signals* also frequently occur when the great circle route lies along or near the shadow band. In cases where the route passes in and out of the shadow band, the extent of the echo dependent the light conditions on one side and the dark conditions on the other side. The study of echoes is very complex, and is not entered into in detail. The reasons for some echo effects have still to be explained. From 30 to 40 metres echoes only occur when the route lies very near or along the shadow band, as the attenuation for these longer waves becomes too great on the daylight or twilight portion of any route crossing the shadow band.

Quick Echo Signals.

Quick echoes of the order of one-hundredth to one-twentieth of a second are frequently heard and appear to be usually caused by the arrival at slightly different times of two or more signals from various scattering sources, or of a main ray reflected signal and a scattered signal, or of a direct surface ray and a scattered signal. This type of echo, of course, has no connection with the round-the-world echoes.

Signal Strength within the "Skip."

As might be expected the diurnal and seasonal changes occurring on scattered signals from a station within the "skip" depend upon the conditions existing on the routes traversed by the scattered signals. If signals from a beam station within the "skip" are scattered back from a distance of a thousand miles in Grade A they will be attenuated on passing through Grade A, on a total route out and back of two thousand miles. Similarly, if the scattering route is in late darkness or Grade D, probably because the edge of the skip is at a great distance at that time, very little energy is scattered back. The signals scattered back from the Dorchester beam directed on New York which traverse out and back, much the same route traversed by the New York beam directed on London, show a marked similarity in diurnal and seasonal changes to the curves for this New York Station.

Magnetic Storms and Sun Spots.

Fig. 9 shows some effects of magnetic storms on signal intensity, and some records of fade out periods observed during the year combined with records of intensity of magnetic disturbances.

An attempt has been made to connect fade out periods with magnetic storms and sunspots, and although in a number of cases the connection has been very definitely established, cases do occur of magnetic storms and sunspots with no accompanying fade out, and fade outs have occurred without any records of sunspots or magnetic storms.

The following table is of interest in connection with the statement made earlier in this paper to the effect that those communications on great circle routes in the neighbourhood of the magnetic poles are more subject to fades lasting several hours than communications on other routes.

TABLE 2.

Communication.	Number of fades observed October, 1927, to October, 1928.
Montreal to London	49
New York ,,	32
Cape Town ,,	4 (1 disturbed condition)
Java ,,	4
Poona ,,	7 (2 disturbed conditions)
Buenos Aires ,,	6

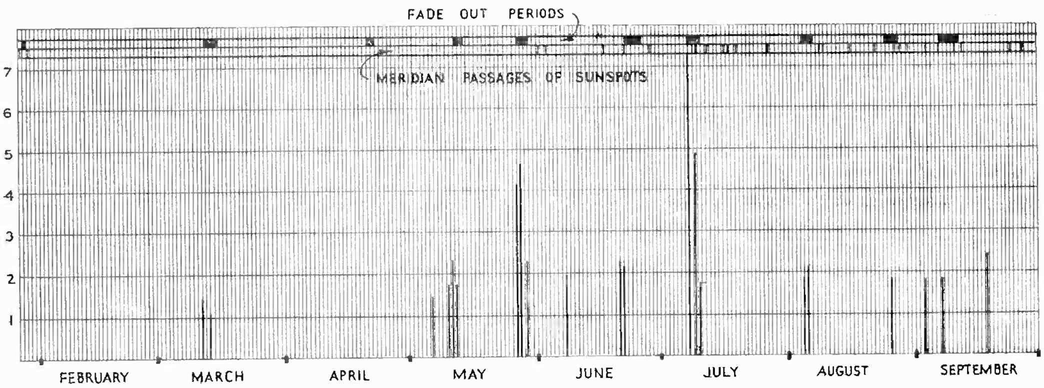
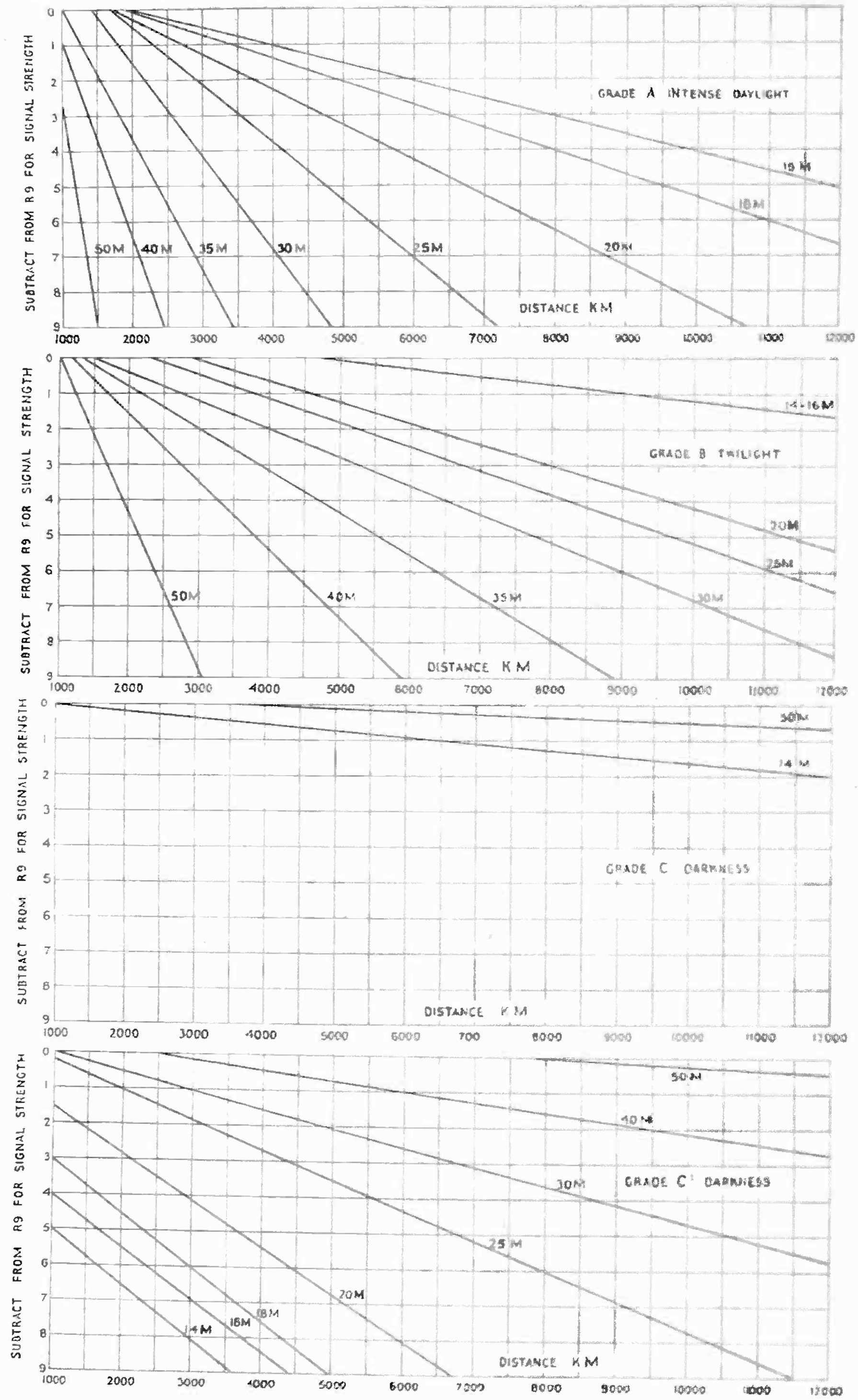


FIG. 9. *Observations taken at Chelmsford of Fade outs and Sunspots, 1928. Vertical lines proportional to Strength of Magnetic Disturbances.*

Application of Experimental Results.

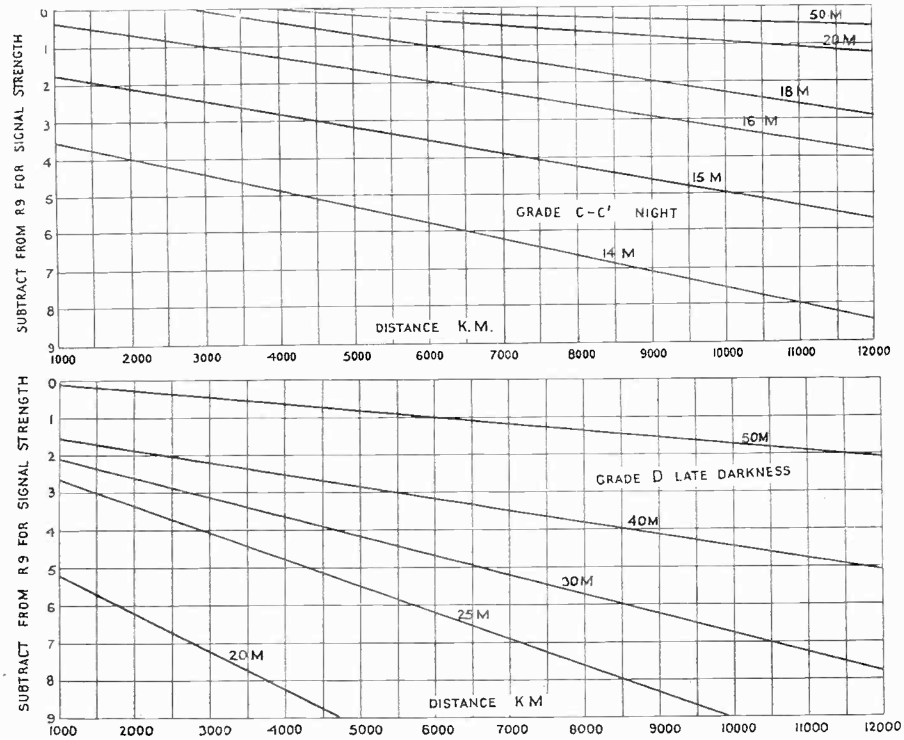
The curves Figs. 10 to 15 have been obtained from an analysis of all the results obtained during the year's interception at Broomfield. They represent an average of the R strengths of signals received under different conditions of day, night and season, and corrections have been made in some cases in order that the curves may apply approximately to the case of a 10 kw. transmitter. Although the results are necessarily approximate due to the variability of short wave signals, and although the signal strengths only apply to a simple type of receiver and aerial as used during the year's interception at Chelmsford, the curves should give a better idea than hitherto possible of the results which may be expected on various long distance short wave communications. The curves are confined to distances beyond 1,000 km. and are applied in the following manner :

The light and dark grades on the shadow charts have been divided into six grades lettered A to D. The R strength of a signal traversing one grade only, may be obtained by subtracting from R9, the figure found in the ordinates of the curve



FIGS. 10, 11, 12 & 13. *Attenuation Curves.*

corresponding to the wavelength required, and the distance traversed in that grade. When two or more grades are included in the signal path, the sum of the ordinates for those grades is subtracted from R9 to give the final signal strength.



FIGS. 14 & 15. *Attenuation Curves.*

The following examples are given for the calculations of the signal strengths on some of the routes at midday during the winter.

LONDON—SAN FRANCISCO, 15 METRES.	Figure to be subtracted from R9.		Final R Strength
2,500 km. of grade B	0	15·5	0
3,700 km. of grade D	9		
2,300 km. of grade C′	6·5		
LONDON—SAN FRANCISCO, 30 METRES.			
2,500 km. of Grade B	·8	5·7	3·3
3,700 km. of Grade D	3·5		
2,300 km. of Grade C′	1·4		

LONDON—MONTREAL ON 16 METRES.

In this case it will be seen that Montreal at midday G.M.T. is just on the border line between Grades D and B. The change in strength will be rapid at this time, from nil at 1100 G.M.T. due to Grade D over Montreal, to R9 at 1300 when the route is 5,000 km. of Grade B only. The small portion of Grade C′ has not been considered in the above cases.

LONDON—MONTREAL, 30 METRES.

At 1100 *G.M.T.*—			
3,300 km. of Grade B	2·5	3·9	5·1
1,700 km. of Grade D	1·4		
At 1300 *G.M.T.*—			
5,000 km. of Grade B	2·8		6·2

LONDON—RIO, 15 METRES.

1,700 km. of Grade B	0	4	5·0
7,500 km. of Grade A	4		

LONDON—RIO, 30 METRES

1,700 km. of Grade B	0	9	0
7,500 km. of Grade A	9		

LONDON—MELBOURNE, 26 METRES.

4,100 km. of Grade B	1·4	2·8	6·2
12,000 km. of Grade C	1·4		

It has been realised for some time that any reduction of signal strength on an all dark route is due to lack of bending or in other words to the "skip effect." Although this effect is most apparent in the case of comparatively short distances, up to, say, 1,000 km., it is frequently present in the case of considerably greater distances when dealing with communications in those dark grades which are reached during the later hours of the night, especially during the winter night. As an example, the skip may extend to 1,000 km. on a wavelength of 25 metres during the early hours of the night denoted by grade C on the shadow charts, but may extend to about 3,000 km. when the route lies in grade C′, and to infinity or rather to the maximum distance possible in grade D when the latter grade is reached. Any calculation of signal strength such as has been attempted by means of the attenuation curves, Figs. 10 to 15, previously described in this paper would be greatly simplified as regards all dark communications if no signals remained after the skip condition was reached. Actually, however, a scattered signal frequently remains. The strength of this scattered residual signal depends on the qualities of the scattering sources available and to a certain extent on the wavelength in use. The scattered signals on the longer wavelengths of about 30 to 40 metres being stronger than those on shorter wavelengths, it is evident that although the attenuation curves (Figs. 0 to 0 in this paper) are true attenuation curves for the daylight grades, they cease to be such in the case

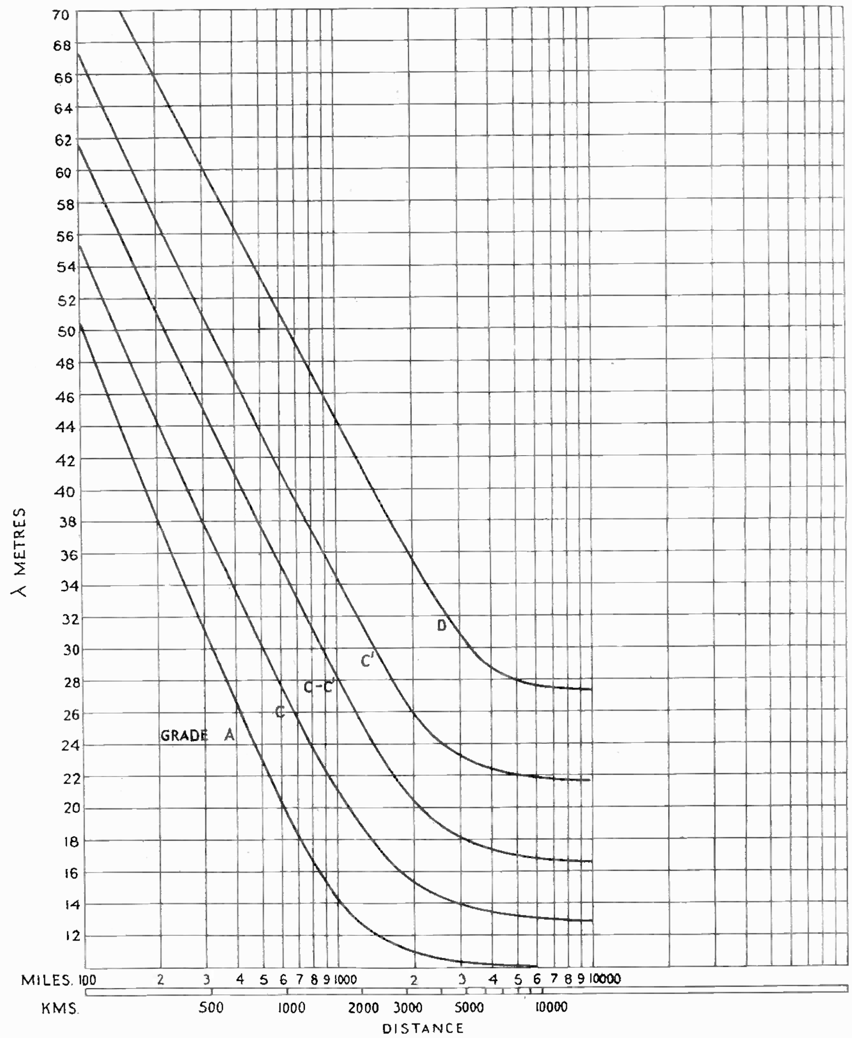


FIG. 16.

of the early night grades on the shorter wavelengths, and in the case of the later night grades on both the shorter waves and also the longer waves extending up to about 40 metres. It will be seen that the night attenuation curves obtained empirically frequently deal with the strength of an entirely scattered signal in those cases in which the complete skip condition has been reached. The best indication of this condition is given by the direction finder and it is made immediately apparent by the absence of a true bearing, the latter being replaced by the bearing of the scattering source. As an example, signals from New York are frequently partially or entirely scattered from the south west at times at which the true great circle route passes through the winter night grades, and similarly signals from the far east with great circle routes through these winter dark grades are frequently partially or entirely scattered back from the lighter grades to the south east. If it is assumed that any scattered signal remaining after the skip condition has been reached is of very little value for commercial work, the prediction of good and bad times for various wavelengths under the various conditions is simplified considerably, and with this idea, a set of curves is now given, Fig. 16, showing from our observations, the normal skip distances for various wavelengths for various distances where the routes lie entirely in the various grades A, C, C—C′, C′ and D. These grades with the corresponding letters have already been given in the shadow charts, Figs. o to o.

Where the route lies half in one grade, say grade D, and half in grade C′, an interpolation may be made between the two curves for these grades. Any point for a given distance and wavelength will represent a skip condition for that wavelength when the point on the chart, Fig. 16, lies to the left of the curve for the trade under consideration.

As an example, at 1,000 miles, 30 metres will be inside the skip in grade C′, but at 2,000 miles 30 metres will be outside the skip in the same grade. These curves representing the border of the skip cannot be taken as fixed, and are liable to variation from day to day with conditions, but they give an average obtained from a large number of observations over a long period. As regards the daylight skip distances for grade A, it should be mentioned that we have had no chance of studying these conditions for intertropical communications, and from some data obtained from Singapore it would appear that the daytime skip for any given wave may be less than in these latitudes.

A VECTOR SOLUTION OF SHORT WAVE FEEDER PROBLEMS

Short wave aerials are usually situated several wavelengths away from the transmitting station to ensure correct radiation, and the power is supplied to the aerial through what is termed a "feeder." This usually consists of two concentric tubes, with the outer kept at earth potential, or two parallel wires, both insulated from earth.

The conditions obtaining in such a feeder cannot be determined by ordinary A.C. theory as applied to circuits containing only concentrated inductance and capacity. In a feeder the electrical energy travels in the form of electro-magnetic waves with equal and opposite currents in the two conductors at any particular section. If the dielectric between the feeder conductors is air, the velocity of such waves is almost equal to that in free space, and in the region of short waves is independent of the frequency.

THE following theory applies to one particular frequency only, and the simplest case to consider is that of a feeder of infinite length with an input EMF of E sin wt as shown in Fig. 1 (A). A and B represent the two conductors of the feeder, the arrow lines represent the electric stress between the conductors, and the + and − signs the electric charges on the conductors. The whole distribution shown travels down the feeder with a definite velocity, without change of form.

Let	L	= Inductance of feeder per cm length in henries.
	C	= Capacity of feeder per cm length in farads.
	u	= Velocity of waves in the feeder.
	i & v	= Instantaneous values of current and voltage at any point.
	I_F & V_F	= Maximum values of current and voltage.
	R_O	= Surge impedance of feeder (to be defined later).

The charge on unit length of feeder at any point is Cv, and the instantaneous current is the charge multiplied by the wave velocity.

That is $i = C.v.u.$

and $$\frac{v}{i} = \frac{1}{C.u} = R_O = \text{constant for any particular feeder.}$$

It can also be shown that $R_O = \sqrt{\frac{L}{C}}$.

A pure resistance R_O would require exactly these values of i and v. Therefore, if we cut an infinite feeder at any point and terminate it with a resistance R_O as shown in Fig. 2, the conditions in the remaining part of the feeder are unchanged. The waves travelling down the feeder are wholly absorbed in the resistance R_O. This is the condition usually aimed at in short wave working, as it gives the maximum efficiency of transmission, the terminal circuit being adjusted to provide an effective load equal to R_0 at the frequency in use.

Since $\quad v = R_0 \, i$

$V_F = R_0 \, I_F$ and V_F and I_F are in phase.

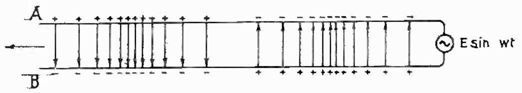


FIG. 1A.

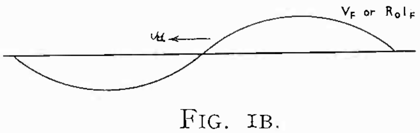


FIG. 1B.

In the general case there may be any number of waves travelling up and down a feeder independently, each with velocity u and for each of them the above relations hold. The resultant disturbance at any point is simply the sum of the disturbances due to the individual waves. The maximum value of current at all points of the feeder will be the same though it will not be reached at the same instant. Three ammeters are usually connected in the feeder at suitable spacing to indicate by their equal reading when the terminal load is correct.

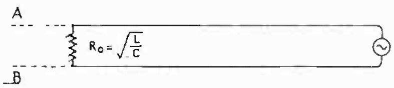


FIG 2.

For any other value of load on a feeder the energy in the incident wave is partly absorbed and the remainder reflected to form a wave travelling in the opposite direction with the same velocity u. This travels back to the input end and is there reflected, and returns to the output end and so on. In the final state there is an infinite series of forward waves and an infinite series of reflected waves; but since all the waves have the same velocity, and the same ratio of current and voltage, we can treat the two series of waves as a single resultant incident wave giving rise to a single resultant reflected wave, and a resultant current in the load, which can be determined by the method given later. Then the whole disturbance at any point of the feeder is the sum of these two resultant waves.

Another way of regarding the problem is this. Let the input terminals be at infinity. Then we can have an infinite train of sinusoidal waves advancing down the feeder supplying current to the output circuit and being partially reflected. Then once the reflected wave is passing a point in the feeder, the steady state will be established at all points between that point and the output terminals. There will be a definite relation between I and V at that point, as regards amplitude and phase, and if we cut the feeder there, and provide these values of I and V from any combination of reactance and resistance, with the necessary internal E.M.F. this steady state will be maintained.

If $\frac{V}{I} = R_X + jX_X = Z_X$, Z_X may be called the equivalent impedance of the load and feeder at this point. *From this we see that the relative values of* I *and* V *and their phase relation at any point are determined entirely by the nature of the load and the surge impedance of the feeder and not at all by the input end. The absolute values of* I *and* V *however, are determined by the E.M.F. at the input end, and the equivalent impedance of the load and feeder at the transmitter.*

Let R = Resistance of terminal load.
X = Reactance ,, ,, ,,
R_O = Surge impedance of feeder.
V & I = the amplitudes of voltage and current in the load.
V_X & I_X = the resultant voltage and current at any point.
R_X & X_X = the effective series resistance and reactance at any point.
V_F & I_F = amplitudes of voltage and current in the forward wave.
V_R & I_R = ditto for reflected wave.

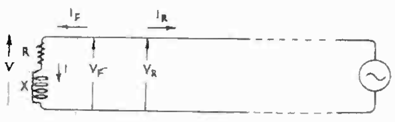


FIG. 3A.

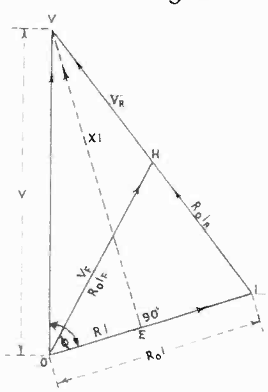


FIG. 3B.

Then with positive directions as shown in Fig. 3 (A).

$$\frac{V_F}{I_F} = \frac{V_R}{I_R} = R_O$$

also V_F & I_F are in phase
and V_R & I_R are in phase.

V = vector sum of V_F & V_R at the load $= \overline{V_F} + \overline{V_R}$

I = ,, difference of I_F & I_R at the load $= \overline{I_F} - \overline{I_R}$

In Fig. 3 (B) O H represents $\overline{V_F}$ at the load.
H V ,, $\overline{V_R}$ at the load.
so that O V ,, V.

For the triangle of currents we know

$$V_F = R_O I_F$$

and is in phase with I_F so that O H represents I_F multiplied by R_O.

Similarly if V H is produced to I making H I = V H = $V_R = R_O I_R$

Then $O\,I = O\,H - H\,I = R_0\,(\overline{I_F} - \overline{I_R}) = R_0\,I$

i.e., O I represents R_0 I in magnitude, and angle V O I $= \phi$ the angle of lag of I behind V.

If we are given the value of R & X at the load to construct this Fig. 3 (B), assume a value for I. Then draw O E $=$ R I and E V $=$ X I. Then O V represents V and angle V O E $=$ angle of lag of I behind V. Mark off O I along O E $= R_0$ I. Join V to I and O to H the mid-point of V I. Then as before stated we have

O V	represents	V
O I	,,	R_0I
O H	,,	V_F and R_0I_F
H V	,,	V_R
I H	,,	R_0I_R

This figure fully determines the conditions existing at the load.

To determine the conditions existing at a point in the feeder at a distance "x" from the load, we know the values of V_F and I_F existing at this point "x" will exist at the load $\frac{x}{\lambda}$ periods later (λ being the wave length in the feeder). Hence, if we rotate O H in a counter-clockwise direction about H through an angle $\frac{2\,\Pi\,x}{\lambda}$ radians (*i.e.*, $\frac{360\,x}{\lambda}$ degrees) we get V_F and I_F for the point x.

Similarly, for V_R and I_R the conditions at x are those existing at the load $\frac{x}{\lambda}$ periods before ; so that we must rotate V H I in a clockwise direction about H through $\frac{2\,\Pi\,x}{\lambda}$ radians.

If we only require the relations of V_X and I_X we can leave O H fixed and rotate V H I in a clockwise direction through $\frac{4\,\Pi\,x}{\lambda}$ radians. V H I will then make a complete revolution for every $\frac{\lambda}{2}$ of the cable.

The resultant V_X and I_X for this point are given by O V and O I as before. Up to the present we have assumed that the transmitter is so far away that only a single incident wave, and a single reflected wave exist at the points considered. But as before mentioned, we can imagine the feeder cut at x and the transmitter connected there, and if this supplies the same values of V_X and I_X that already existed there, the same state of things will be maintained. The feeder and load will therefore behave as an impedance $= \frac{V}{I}$ as regards the transmitter. This may be termed the equivalent impedance of the feeder and load at the point " x " and will obviously vary with the distance x.

We can also imagine the feeder cut at " x," and the feeder beyond this point, and the load, replaced by the equivalent impedance, and the original state of things would persist in the remaining portion of the feeder.

An example is worked out in Fig. 4 for an inductive load in which $R=X=R_0$, but the remarks below apply to any inductive load.

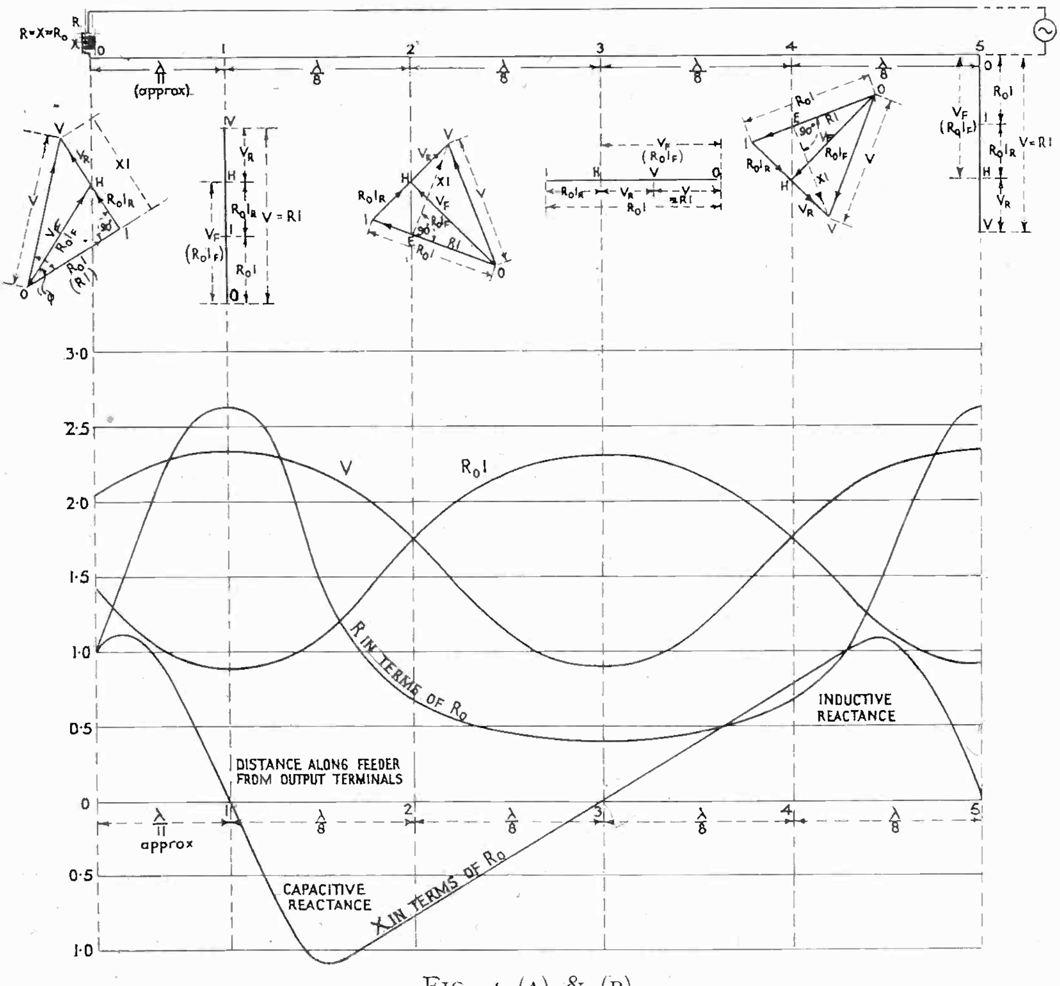


FIG. 4 (A) & (B).

At a distance less than $\frac{\lambda}{4}$ from the load O H and V H I come into line as shown in (A) 1. V and I are in phase, V (*i.e.*, O V) having its maximum value and I (*i.e.*, O I) its minimum value. Hence the equivalent impedance is a maximum, and is a pure resistance. At the point 2, $\frac{\lambda}{8}$ further from the load O H is at right angles to V H I and ϕ reaches its maximum negative value. O I = O V, *i.e.*, $V = R_0 I$. The equivalent impedance is equal to $\frac{V}{I} = R_0$ in magnitude but is capacitive. $\frac{\lambda}{8}$ further back at 3, O H and V H I are in line again, but now V has its minimum value, and I its maximum value. Hence the equivalent impedance is a minimum, and is a pure resistance. If R_1 and R_3 are the values at 1 and 3 then $\sqrt{R_1 R_3} = R_0$. $\frac{\lambda}{8}$ further back at the point 4, O H and V H I are at right angles again, the equivalent impedance is equal to R_0 but this time it is inductive. At the point 5, $\frac{\lambda}{8}$ further back still we get figure 5 which is similar to 1 except that all phases are reversed. Beyond this point the sequence will be repeated.

The curves of 4 (B) show how the resultant voltage and current vary from point to point on the feeder. It will be seen from these that three ammeters spaced about $\frac{1}{8}\lambda$ or $\frac{3}{8}\lambda$ apart will always give unequal readings while any reflected wave exists. Ammeters spaced $\frac{1}{4}\lambda$ apart might give equal readings even with strong reflected waves if they were situated at points such as 2 and 4.

In Fig. 4 (B) are also shown the variation in equivalent series resistance and reactance of the feeder and its terminal load. These are determined by drawing V E perpendicular to O I when $OE = R_X I$, and $EV = X_X I$ or

$$\frac{OE}{OI} = \frac{R_X I}{R_0 I} = \frac{R_X}{R_0} \text{ and } \frac{EV}{OI} = \frac{X_X}{R_0}$$

The case for any other load can be similarly worked out, but the general sequence can be deduced from the present set of curves. Thus, if the load is capacitive, it is equivalent to having the load situated in the section 1—3.

Pure Resistance Load.

If the load is a pure resistance it must be situated at 1 or 3, according as it is greater or less than R_0. If it is equal to nR_0, then at points along the feeder whose distances from the load are $\frac{1}{2}\lambda$, 1λ, $1\frac{1}{2}\lambda$, etc., the equivalent impedance is a pure resistance nR_0; whilst at points whose distances from the load are $\frac{1}{4}\lambda$, $\frac{3}{4}\lambda$, $1\frac{1}{4}\lambda$, etc., it is a pure resistance $= \frac{1}{n} R_0$.

E. GREEN.

PRACTICAL DETERMINATION OF THE TERMINAL IMPEDANCE OF SHORT WAVE FEEDERS

In the previous article a vector diagram was developed showing how the voltage and current at a given point in a feeder are related to the voltage and current at any other point.

It is the purpose of this article to show that this diagram may be completely determined in a practical case from the three current readings, normally taken on a standard feeder system, and that the fine adjustment to be made at the last feeder junction to reduce reflection to the practical minimum may be found in this way.

THE proposition which is used in the following pages is as follows :—

If OV and OI (Fig. 1) represent respectively the voltage at a given point A, and the product of the current at that point and R_0 (the surge impedance of the feeder) the conditions at any other point at a distance x from A may be found by rotating the line VI about its centre H through an angle $\frac{4\pi x}{\lambda}$ radii to a new position V^1I^1. The vectors OV^1 and OI^1 will represent current and voltage at the new position. (N.B.—direction of rotation anticlockwise when moving towards the output end)

Data Required. Three ammeter readings I_a, I_b and I_c. Distances between ammeters d_1 and d_2. Distance from last ammeter to termination ($d3$).

To Find the relation in terms of R_0 between voltage and current at the terminating impedance.

Construction (Fig. 2). Draw a circle of convenient radius. Draw radii HA, HB and HC, so that

$$\widehat{AHB} = \frac{4\pi d_1}{\lambda}$$

$$\widehat{BHC} = \frac{4\pi d_2}{\lambda}$$

Along A B mark off BD so that

$$\frac{BD}{DA} = \frac{I_b}{I_a}$$

Along AB produced mark off BK so that

$$\frac{BK}{KA} = \frac{I_b}{I_a}$$

With centre E and KD as diameter describe a circle.

Similarly along CB make

$$\frac{BF}{FC} = \frac{I_b}{I_c}$$

and along CB produced make

$$\frac{BL}{LC} = \frac{I_b}{I_c}$$

and with centre G describe a circle having FL as diameter. Let these two circles intersect at O, then $OA : OB : OC = I_a : I_b : I_c$.

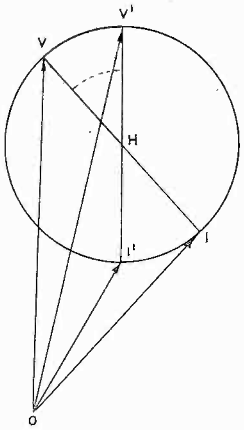


Fig. 1.

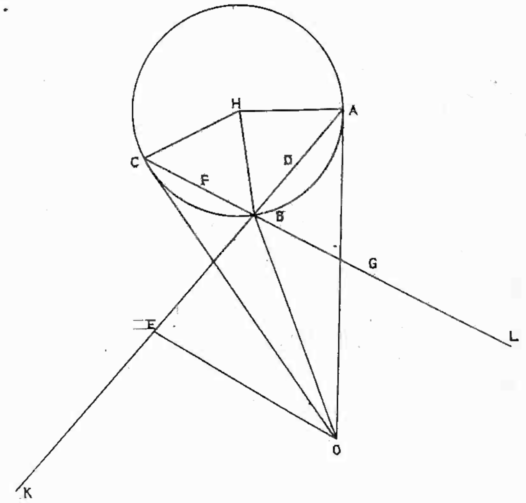


Fig. 2.

Proof.

Let $BD = b$ and $AD = a$

Then $\dfrac{BD}{AD} = \dfrac{b}{a}$ $\qquad \dfrac{BK}{AK} = \dfrac{b}{a}$

And $AK = BK + BA \qquad = BK + (a + b)$

Whence $BK = \dfrac{b\,(a + b)}{a - b} \qquad DK = \dfrac{b\,(a + b)}{a - b} + b \qquad = \dfrac{2ab}{(a-b)}$

$$ED = \frac{ab}{(a-b)} = EO.$$

And $EB = ED - HD \qquad = \dfrac{ab}{(a-b)} - b \qquad = \dfrac{b^2}{(a-b)}$

And $BA = ED + DA. \qquad = \dfrac{ab}{(a-b)} + a \qquad = \dfrac{a^2}{a-b.}$

Now $\quad OB^2 = EO^2 + EB^2 - 2EOEB \cos \widehat{OEB}$

$$= \frac{a^2 b^2 + b^4 - 2ab^3 \cos \widehat{OEB}}{(a-b)^2}$$

$$= b^2 \left\{ \frac{a^2 + b^2 - 2ab \cos \widehat{OEB}}{(a-b)^2} \right\}$$

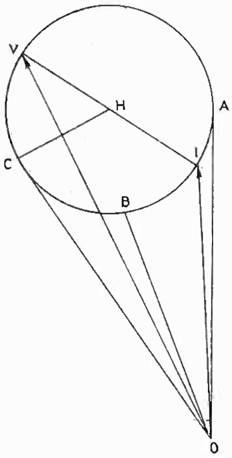


FIG. 3.

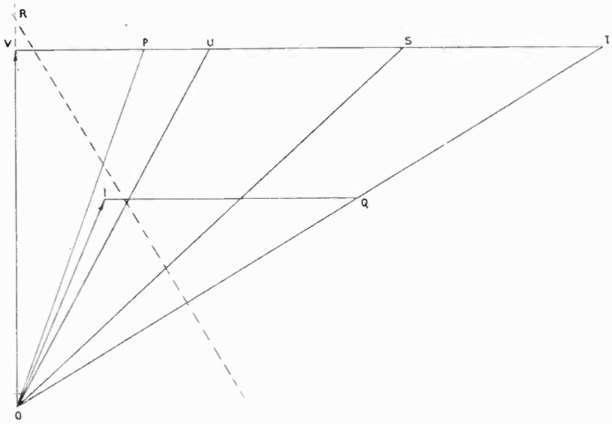


FIG. 4.

And $\quad OA^2 = EO^2 + EA^2 - 2EOEA \cos \widehat{OEA}$

$$= \frac{a^2 b^2 + a^4 - 2a^3 b \cos \widehat{OEA}}{(a-b)^2}$$

$$= a^2 \left\{ \frac{a^2 + b^2 - 2ab \cos \widehat{OEA}}{(a-b)^2} \right\}$$

Whence $\quad \frac{OB^2}{OA^2} = \frac{b^2}{a^2} \qquad \frac{OB}{OA} = \frac{b}{a} = \frac{BD}{AB} = \frac{I_b}{I_a}$

Similarly $\quad \frac{OB}{OC} = \frac{I_b}{I_c} \qquad OA : OB : OC = I_a : I_b : I_c.$

Now from H draw HI, so that

$$\widehat{CHI} = \frac{4\pi d_3}{\lambda}$$

Draw the diameter IHV.

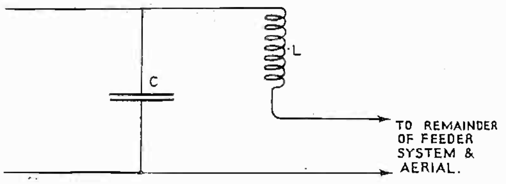


FIG. 5.

Then OV and OI will represent the voltage and current vectors at the last junction and completely define (in terms of R_o) the impedance of the feeder and aerial system from that point onward.

TO FIND the necessary adjustment at the last junction.

For ideal termination OI must coincide with OV. The necessary changes to the inductance (L) and the capacity (C) may be determined as follows.

DATA REQUIRED. Length " l " of each condenser tube

CONSTRUCTION (Fig 4) From V draw a line at right angles to OV and make

$$\widehat{VOP} = \frac{2\pi l}{\lambda}$$

From I draw IQ at right angles to OV, making IQ = 2VP.

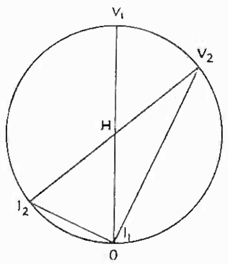


FIG. 6.

Then OQ = $R_o \times I_l$ where I_l is the current through inductance L and the remainder of the feeder system (Fig. 5).

PROOF.—Each condenser tube is a length of feeder of surge impedance R_o terminated by an infinite impedance (open circuit). The vector diagram is as in Fig. 5. The current through the terminating impedance being zero I_1 coincides with O. To find the conditions at a distance " l " from the open end rotate V_1 I_1 clockwise about its centre through an angle $\frac{4\pi l}{\lambda}$ obtaining the new positions V_2 and I_2.

Since $HV_2 = HI_1$

$$I_2 \widehat{V_2 O} = \widehat{HOV_2} = \tfrac{1}{2} I_2 \widehat{H} I_1 = \frac{2\pi l}{\lambda}$$

VP in Fig. 4 represents in length the product of R_o and the current to one condenser tube. IQ represents the product of R_o and the current to both tubes, *i.e.*, $R_o \times I_c$ but is drawn in the negative direction.

Now vectorially OQ = OI + IQ = $I \times R_o - I_c \times R_o = I_l \times R_o$

Now Bisect OQ at right angles and let the bisector cut OV at R. With centre R describe an arc from Q cutting VP produced at S. Variation of the value of L will make Q move along the arc towards S and to make Q coincide with S the inductance must be varied in the ratio VS/VT (T being the intersection of OQ and VS produced).

Since $$VS/VT = \frac{\tan VOS}{\tan VOT} = \frac{L_1/R}{L_2/R} = L_1/L_2$$

(where L_1 = value of inductance as set
L_2 = ,, ,, ,, required
R = impedance of remainder of feeder system.

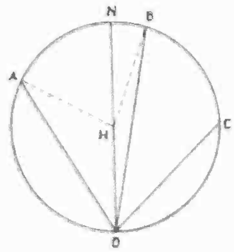


FIG. 7.

Now Bisect VS at U.

If l is altered so that

$$\widehat{VOU} = \frac{2\pi l}{\lambda}$$ then the current I_c will be equal to SV and I will then coincide with V.

SUMMARY. To effect correct termination change L in the ratio VS/VT.

Change "l" in the ratio $\widehat{VOU}/\widehat{VOP}$.

Note.

This construction can give very satisfactory results in practice but it has its limitations. For instance the positions of the points G and E are fundamentally important but depend on the accurate determination of a small difference between two comparatively large observed values. It is therefore necessary to make careful calibration of the feeder ammeters at the frequency of measurement. For more accurate work a fourth meter might be introduced to check observational error. This would give—for the point O the intersection of three arcs instead of two and hence three alternative positions from which could be taken—as a fair mean—the centre of the circle passing through the three of them. In addition no account is taken in the original proposition of the effects of the small losses in the feeder due to resistance and leakance. Since however the impedance of a pair of aerials varies to some extent with temperature and windage, and the effect on reflection of expansion and angle boxes in the feeder must be appreciable, a complete and permanent elimination of reflection cannot be obtained.

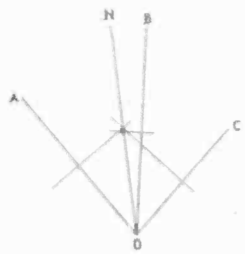


FIG. 8.

Another point that has been taken for granted in Fig. 4, is that the load represented by the remainder of the feeder is for all practical purposes a resistance. For the normal two-to-one junction this should be equal to $\frac{1}{2}$ R_o and its approximation to this value is indicated by the margin by which point R (Fig. 4) fails to coincide with V. Actually this load will rarely be purely resistive but will be equivalent to a resistance in series with a small reactance (capacitative or inductive). So long as this is reasonably small with regard to $L\omega$ no serious error will be involved by neglecting it. Even should it be large the error does not occur until the computation of the required value of L for the proper termination. Any small reactance in series with the load is also in series with that load and hence

$$\text{instead of VS/VT} = \frac{L_1}{L_2}$$

$$\text{the equation becomes} \quad \text{VS/VT} = \frac{L_1\omega + X}{L_2\omega + X}$$

Where X is this unknown reactance (if it were considerable its actual value could be determined from a separate set of ammeter readings).

There is however one factor which can seriously upset calculations and that is the actual wavelength along the feeder. As this will be slightly different from the wavelength of radiation a definite measurement should be made on the feeder itself. This can conveniently be done by open-circuiting the feeder at the distant end and taking three ammeter readings as before, calculating the wavelength from a construction based on Fig. 6, where on account of the fact that the feeder is open-circuited O will be on the circle generated by the rotation of VI.

Hence if OA, OB and OC (Fig. 7) are three ammeter readings, all four points O, A, B and C will be on a circle and

$$\widehat{AOB} = \frac{2\pi d_1}{\lambda}$$

$$\widehat{BOC} = \frac{2\pi d_2}{\lambda}$$

$$\left\{ \text{Because } \widehat{AOB} = 1/2\ \widehat{AHB} \text{ and } \widehat{AHB} = \frac{4\pi d_1}{\lambda} \right\}$$

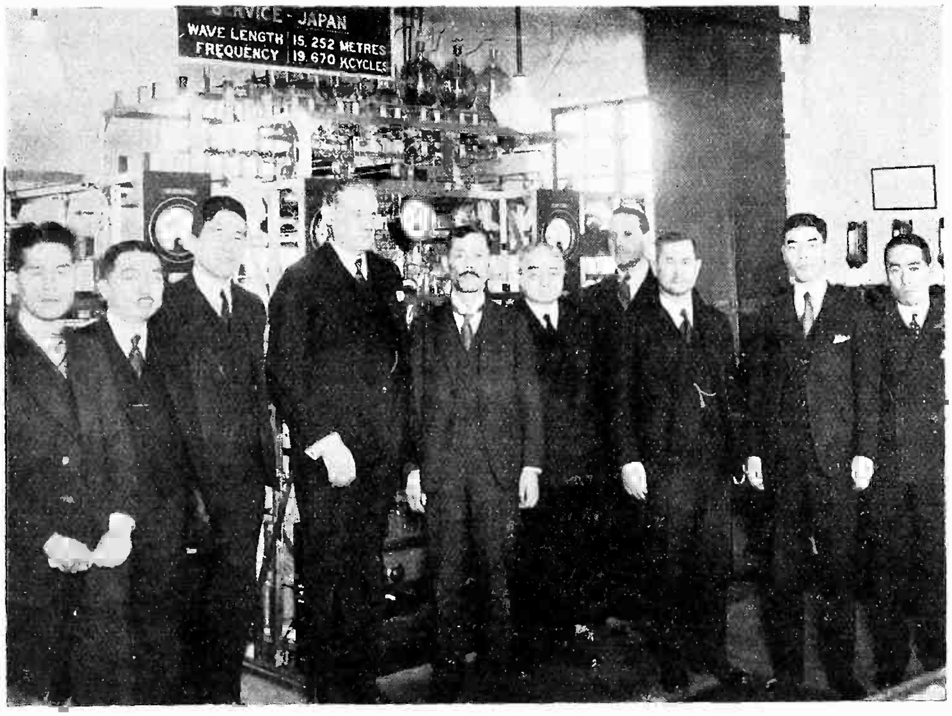
Select then an arbitrary value for λ and draw OA, OB and OC at the angles corresponding to this value. Draw the perpendicular bisector of OA and find the position of M the intersection of the perpendicular bisectors of OB and OC.

Let OA remain fixed and repeat for successive values of λ (thus obtaining the locus of the point M). Continue until this locus cuts the perpendicular bisector of AO. This will give a value for λ but on account of observational error in meter readings the accuracy of the result may not be better than 2 per cent. A more exact value is given by calculating for a close succession of values of λ the angular distance from A of the nearest antinode of current working backwards from the node which necessarily exists at the far end. This antinode should appear on the diagram as a diameter and hence should pass through H. If the distance from A is many wavelengths this line (ON Fig. 7) will move exceedingly rapidly with the value of λ in comparison with the movement of say OB or OC. With very little difficulty a value for λ may be found such that ON passes through the centre of the small triangle formed by the three bisectors of OA, OB and OC (Fig. 8). If ammeter readings are taken with care this triangle will be reasonably small and an accuracy of 1/10th of 1 per cent. may be expected in the resultant value of λ. Experiments on 24 and 28 metres give a value of λ in the feeder equal to 97·64 per cent. of its value in space.

L. T. Bird.

MARCONI NEWS AND NOTES

INTERNATIONAL NAVAL CONFERENCE IN LONDON



His Excellency Mr. Reijiro Wakatsuki (fifth from the left), Japanese Envoy to the International Naval Conference, and party, at the Marconi Beam Station at Dorchester.

Speeches Broadcast Throughout the World.

The speeches of the King of England and the principal national delegates at the opening of the London Naval Conference on January 21st were broadcast through the agency of the British Broadcasting Corporation, and heard by wireless listeners practically throughout the civilised world. A new record in simultaneous world broadcasting was established, and in this feat the Marconi Company played a prominent part in several ways.

Long wave and short wave omnidirectional stations and the Marconi short wave Beam stations at Dorchester and Bodmin were used in Britain to broadcast the speeches to all parts of the world for relaying from more than 200 oversea stations.

The high power long wave station at Daventry, 5XX, supplied by the Marconi Company to the British Broadcasting Corporation, was picked up by many Continental Stations. Further afield, the programme transmitted by the experimental short wave broadcasting station 5SW at the Marconi Works, Chelmsford, was well received and re-broadcast. Of this station, the *Wireless World*, the well-known

British wireless journal, stated :—

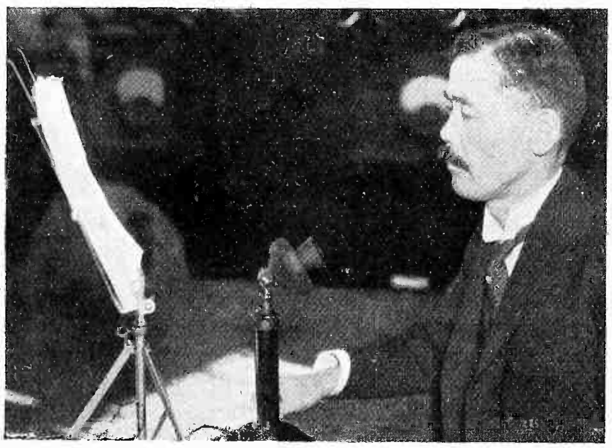
> " The honours go to 5SW. Several stations on the Continent which had arranged to take the broadcast by land line, chose the less expensive but equally efficient method of tuning in Chelmsford. Among the stations which preferred this method were Turin, Naples, Stockholm and Vienna, the last two starting with landline, but resorting to 5SW because the transmission was better."

Listeners in more distant countries also heard the broadcast direct from 5SW. Apart from the Naval Conference broadcast the Marconi Company is constantly receiving excellent reception reports of this station from short wave listeners as far afield as South Africa, India and Australia.

Beam Broadcasting Link.

As in the case of previous international broadcasts from Great Britain—such as the broadcast of the Thanksgiving Service at Westminster Abbey for the King's recovery in July last—Canadian listeners were well served by the Marconi Beam station at Bodmin, which provided a highly efficient transatlantic " link." The signals were strongly received by the Canadian Marconi Company's Beam receiving station at Yamachiche, and very successfully re-broadcast throughout the Dominion by a chain of 25 stations.

The programme was also received by Beam in Australia, the Canadian Marconi Company relaying the signals received by transatlantic Beam over the Montreal-Melbourne Beam circuit.



The Japanese Envoy at the Microphone.

Britain - Japan Beam Telephony.

At a later stage during the Naval Conference, the Marconi Beam system was again brought into use to enable His Excellency, Mr. Reijiro Wakatsuki, the Japanese Envoy, to speak by wireless telephone from Britain to Japan.

The Marconi wireless telephone installation was connected to the Beam telegraph aerial used for telegraphy with Japan, and reports received indicate that Mr. Wakatsuki's voice was heard as clearly in Japan as it was in the little room at Dorchester. Not only was it heard at the Beam receiving station at Yokkaichi, but it was broadcast to the whole Japanese nation through the Japanese Broadcasting

Association's chain of stations covering Japan from Sendai in the North, Tokyo, Osaka, Nagoya, and Hiroshima, to Kumamoto in the South.

As Mr. Wakatsuki was speaking the members of his staff who were with him received reports by wireless telegraph every minute stating that his voice was being heard perfectly with every word clear and distinct. At the conclusion of Mr. Wakatsuki's speech, one of the party went to the telephone and said : " Hello, Japan. We are glad that you have had the opportunity of hearing Mr. Wakatsuki's speech. How did you hear him ? "

Back came the immediate reply by wireless telegraph—no Beam telephone transmitter being yet available in Japan : " Perfectly. We are very gratified that, thanks to the wonderful achievement of the Beam wireless system of telephony we have been able to hear our envoy himself speaking to us."

Mr. Wakatsuki was equally pleased at the opportunity that had been given him, and in the course of his speech, said : " I rejoice that the completion of the Beam system by the Marconi Company has now made possible the direct transmission of speech between England and Japan, separated by 10,000 miles of sea and land, and I am very happy to avail myself of this wonderful invention to address my fellow countrymen at home while I am in London on this important mission. A wonderful invention by scientists such as this, which can carry the human voice from London to Tokio, should inspire us all to redouble our efforts to overcome any obstacles that hinder the world's progress to peace."

Beam Transmitting and Receiving Aerials.

Mr. Wakatsuki spoke into an ordinary Post Office telephone as he would have done in telephoning from his home to a friend. The telephone was connected to the modulating panel of a Marconi short-wave Beam transmitter connected to the aerials by means of which the Beam signals are directed towards Japan. A programme of gramophone records, including songs in Japanese and orchestral pieces, was transmitted for re-broadcasting at the close of Mr. Wakatsuki's address.

In Japan the signals were received on the Beam receiving aerial at Yokkaichi station and transferred to the landlines connecting up all the Japanese stations from which the speech was broadcast.

There are seven transmitters at the Dorchester Beam station, and if there were suitable receivers in the Argentine, Brazil, United States of America, Egypt, Siam, or any of the other countries with which Dorchester carries out Beam telegraph services, wireless telephone conversations could be carried out with any and all of them through this station without interfering with the telegraph services. The Dorchester station in fact, might be regarded as a wireless telephone switchboard, through which it would be possible, with suitable equipment, to speak to all four corners of the world either at one time or to one country after another as quickly as one could be switched through from Rio de Janeiro to New York and from New York to Cairo and Tokyo.