JOURNAL OF
The British Institution of Radio Engineers

(FOUNDED IN 1925 - INCORPORATED IN 1932)

" *To promote the general advancement of and to facilitate the exchange of information and ideas on Radio Science.*"

Vol. X (New Series) No. 10 OCTOBER 1950

PROPAGATION OF METRIC WAVES BEYOND OPTICAL RANGE*

by

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A paper read before the London Section on April 20th, 1950.

SUMMARY

A qualitative survey of tropospheric and ionospheric propagation in the frequency band 30-200 Mc/s. Theoretical considerations are limited to explanations of the basic principles involved.

A knowledge of the easily recognized meteorological conditions associated with variations in tropospheric propagation is shown to be useful in short-term prediction of radio conditions. Owing to the random nature of such conditions, however, the extended ranges obtained will, in general, be disadvantageous because of interference problems between fairly widely separated transmitters.

A selection of long-term observations over various land and sea paths, both tropospheric and ionospheric, is presented in graphical form and results discussed.

1.0. General

As the result of the researches of a number of workers,[1] it is now possible to calculate, with sufficient accuracy for practical purposes, the field strength at any point within optical range, given antenna type, power and height above ground. Such transmission is, of course, 100 per cent. reliable and, generally speaking, unaffected by atmospheric conditions. Complications are mainly brought about only by variations in terrain and ground conductivity. The present paper is concerned only with propagation beyond the line of sight into the less reliable zones.

The frequency band under consideration, namely 30-200 Mc/s, which is important owing to its choice for various short-range communication, broadcasting (television, F.M., etc.) and mobile services, includes that part of the spectrum where ionospheric propagation (used for long-distance services) effectively ceases. Unfortunately, it is not possible to set a definite dividing line, within the band, where this cessation occurs. As is pointed out in greater detail later, ionospheric propagation over long distances, which may at times be quite reliable at 30 Mc/s, becomes progressively less reliable as frequencies of the order of 60 Mc/s are reached. In fact, apart from a few geographical locations, chiefly in tropical zones, the effects of ionospheric propagation may generally be ignored at frequencies exceeding 60-70 Mc/s.

2.0. Tropospheric Propagation. Basic Principles

By contrast, however, over the *whole* of the band of 30-200 Mc/s the effects of *tropospheric* propagation in extending range are equally important, both from the point of view of frequency of occurrence and of duration. For this reason this form of propagation will first be considered.

Although the present paper is concerned with frequencies up to approximately 200 Mc/s, in general tropospheric effects on propagation will be similar on frequencies up to at least 500 Mc/s. It should also be made clear that such effects do not " commence " at 30 Mc/s, since they can be detected on much lower frequencies.

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* Manuscript received April 1st, 1950.
U.D.C. No. 621.396.812 : 621.3.029.62.

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The theories of tropospheric propagation have in recent years been put forward at length by a number of workers[2] and it is therefore only proposed here to outline the basic principles.

Such propagation is known by a number of rather loosely used terms, of which can be mentioned anomalous propagation, super-refraction, trapping, guiding, ducting, etc., most of which are intended to refer to rather special cases of tropospheric propagation. In the present case it will probably be most discreet to use the broader terms " super-refraction " and " trapping."

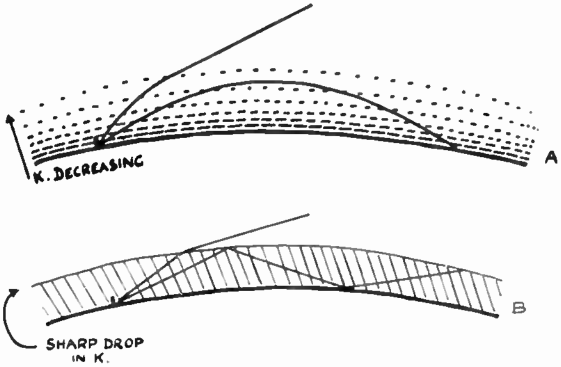

Fig. 1.—Illustrating principles of tropospheric propagation and ray tracks for (a) steep negative gradient in dielectric constant K. (b) Sudden drop in K at given height producing reflection. (Ground reflection is also shown.)

Propagation around the earth's curvature takes place because the radio wave undergoes refraction and/or reflection as the result of small changes in the dielectric constant (K) and hence refractive index, with height, of the lower atmosphere. For downward bending of the low-angle ray track it is necessary that the dielectric constant *decreases* with height (Fig. 1 (*a*)). This condition is satisfied to a varying degree according to the weather system prevailing over the path under consideration. If there is a relatively gradual decrease in K with height there will be a curved ray track. A sharp drop in K at a given height will, in addition to sharp refraction, produce reflection of rays arriving at the discontinuity at angles greater than a critical angle of incidence (Fig. 1 (*b*)).

The actual dielectric constant of air is very little more than unity, and although the changes in K with height are at most only a few hundred parts in a million they are sufficient to produce the required small deviations of the ray tracks.

The presence of water vapour increases the dielectric constant of air and, in fact, the variations with which we are concerned are mainly controlled by the moisture content or humidity of the lower atmosphere. The K of moist air is given by the relation

$$K - 1 = \frac{160}{T} \times 10^{-6}\left(P + \frac{4800\,e}{T}\right) \quad \ldots\ldots(1)$$

where P is the total atmospheric pressure in millibars (mb), *e* the partial pressure of water vapour in mb and T the absolute temperature. Thus it will be seen that the dielectric constant is also inversely proportional to the temperature and proportional to the pressure, so that a decrease of pressure or increase of temperature with height will produce downward bending of the radio ray. Pressure always decreases with altitude in the atmosphere and under what can be termed standard conditions, so also does temperature, these two variables thus having opposite effects on the bending of the radio ray. The overall effect is, however, that in the standard atmosphere K decreases with height by about ·000037 per 1000 m. This decrease with height only produces insignificant curvature of the radio ray.

In the troposphere the vertical distribution of water vapour content and temperature is subject to considerable variation with time. Water in droplet form, such as fog and rain, has little effect on the frequencies we are considering, but on centimetric frequencies produces absorption, scattering, etc. It is the invisible water vapour content which is important in deciding the dielectric constant.

The amount of water vapour held by air is dependent on the *temperature* of the air.

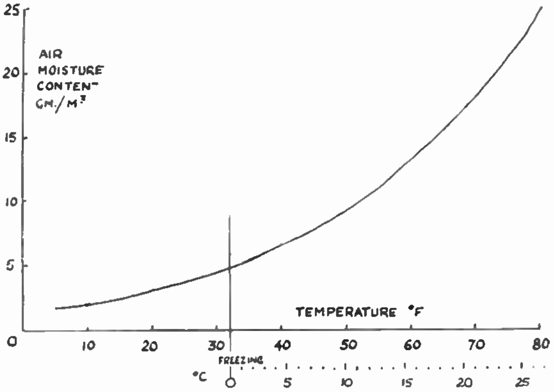

Fig. 2.—Relationship between air temperature and absolute humidity.

Meteorologists refer to the water vapour content in terms of a percentage of relative humidity. The Relative Humidity specification does not take into account temperature. The relationship between the moisture content or absolute humidity and temperature is shown in Fig. 2. The importance of temperature in deciding the moisture content is quite apparent from this curve. It will be noted that the content increases rapidly at temperatures over freezing point. Because the temperature of the atmosphere falls with height at the rate of some 6·5 deg. C per km, the moisture content at heights exceeding 2 km, where temperatures near or below freezing point are normal, is very low and consequently has little effect on K. For this reason, in tropospheric propagation, except under very abnormal conditions, we are mainly concerned with that part of the atmosphere from ground level to 1·5 or 2 km—unlike ionospheric propagation, where heights exceeding 100 km are normally involved. This fact will readily be seen to be important in the question of aerial height, for, as the steepest gradients or discontinuities occur at low altitudes, the ray curvature will normally be less with increased height until a point is reached where the rays are not returned to earth or do not follow the earth's curvature. There will therefore be an optimum aerial height for a given set of weather and ground conditions if full advantage of tropospheric propagation is to be obtained.

3.0. Expected Coverages

Whilst, given accurately the weather information, ground characteristics, etc., over a given non-optical path, it is possible laboriously to calculate to a fair approximation the actual field strength obtained, in general the variations of weather are so continuous that such a proposition is far from practical. A statistical approach would appear to be the only method to adopt in planning the expected coverage of a transmitter under varying tropospheric conditions. Thus, with a knowledge of the climate over a given path, minimum and maximum effective ranges, with time percentages for either, could be specified for various seasons and similarly limits of field strength variation in terms of the product free-space values and a " path factor " might be stated. As insufficient data in this connection are available at the present time it is proposed to make this the subject of a future paper.

It is an undeniable fact that in most circumstances the effects of tropospheric propagation are a nuisance rather than a blessing, particularly for the exacting requirements of television, as the coverage of a given transmitter becomes as uncertain as the weather ! This fact is important when questions of interference between rather widely separated stations are concerned. However, because tropospheric effects are mainly confined to the lower atmosphere and because a given set of weather conditions seldom covers a radius exceeding 300 km, ranges exceeding 350 km are very exceptional and can generally be ignored. For reasonable freedom from interference by tropospheric effects in temperate latitudes it would therefore seem desirable that stations operating on the same frequency should be not closer than 400 km. Adequate discrimination should then be obtained by the use of simple directional aerials for receivers located *between* transmitters at this spacing.

4.0. Modified Index of Refraction (M)

Instead of using the dielectric constant or refractive index as such in computing the degree of refraction, etc., which will take place under a given set of conditions, it has become the practice to make use of a modified refractive index, which takes into account the effect of the earth's curvature. This unit is given by the relation (see Appendix)

$$M = \left(n - 1 + \frac{h}{a}\right) 10^6 \ldots\ldots\ldots\ldots (2)$$

where a is the earth's radius, h the height of point of observation above earth, and n the index of refraction (simply related to the dielectric constant by $n = \sqrt{K}$). At ground level M becomes, of course, merely $(n - 1)\ 10^6$.

Values of M range between 200 and 500. In a well-mixed atmosphere M has a linear positive gradient with height owing to the presence of the term $\frac{h}{a}$ (Fig. 3 (*a*)). Under conditions of stratification and steep negative gradient in refractive index, M has a negative slope at ground or elevated levels according to the actual weather system prevailing and the radio ray will be guided around the earth's curvature (Figs. 3 (*b*), (*c*) and (*d*)).

5.0. Radio Meteorology

A knowledge of the fundamentals of meteorology will be found a distinct advantage in the short- and long-term forecasting of tropospheric radio conditions. It is, of course, beyond the scope of the present paper to go into detail in this respect and there are adequate references on the subject.[3] We may, however, at this point usefully consider and summarize a few of the main features from the radio point of view :

(*a*) For maximum extended coverage, requirements are that there should be a condition of high humidity at ground or low level followed by a rapid *drop* in humidity with height (which can be termed a humidity contrast) or an increase in temperature with height (temperature inversion). (Generally, though not always, the two conditions occur together.) Obviously, also, these conditions will have to apply to a wide area.

(*b*) For standard coverage, i.e., no extension of range by tropospheric effects, a well-mixed atmosphere, where the lapse rate of temperature is high and that of humidity low, is required.

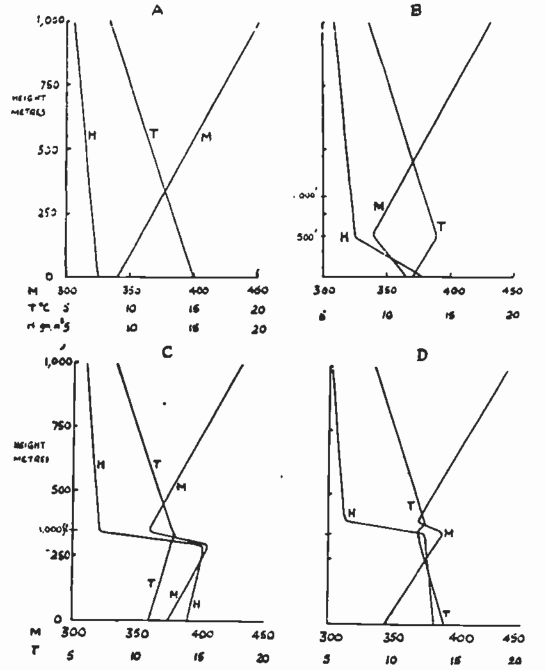

Fig. 3.—"Smoothed" "M" and related humidity and temperature gradients for typical meteorological systems. (In practice unimportant minor and continuous variations with height are in addition recorded.) (a) "Standard" atmosphere with no temperature inversions or humidity contrasts. (b) Steep negative gradient in humidity with temperature inversion; (c) and (d) Sharp drop in humidity with temperature inversions; (d) with elevated temperature inversion.

The meteorological conditions might be specified, simply, for (*a*) as fine, warm, anticyclonic, settled weather and for (*b*) as rough, cold, cyclonic or frontal weather. Between these two extremes we shall, of course, have a wide selection of possible systems, where the forecasting of probable tropospheric radio conditions will be more difficult from a purely visual observation of the sky.

The anticyclone always provides the most marked super-refraction and trapping. Anticyclones are, of course, areas of high or very high barometric pressure, wherein the weather is generally fine and settled, winds very light and cloud, if any, of a low thin stratus type. The winter anticyclones provide rather more stratus cloud and often fog, but in summer fine clear weather is usual. Anticyclones cover larger areas than depressions and move much more slowly. Once formed they often remain almost stationary for two or three days and on occasions as long as ten days or more. Hence under these conditions extended ranges by tropospheric trapping are reasonably reliable for comparatively long periods of up to several days.

Foggy weather generally is an indication of good conditions for super-refraction, etc., on the frequencies now being considered (though as pointed out earlier on centimetric waves this is often the reverse). Obviously the fog indicates air of over 100 per cent. relative humidity and generally above the fog there is clear sky and a sharp drop in the humidity.

In summer or warmer weather generally, tropospheric effects will be considerably more prevalent than in the cold winter months.

Considering diurnal variations, whilst on the average there tends to be greatest trapping possibilities from an hour or two after sunset with a peak in the early morning hours, the actual conditions on any one occasion are more decided by the weather system prevailing than by the time of day.

Obviously, after sunset, in stable weather, conditions are most suitable (over land) for the formation of temperature inversions, for as the ground cools off the air in contact with it is likewise cooled while the air above remains at almost its daytime temperature. With the sun's heating removed also at night there will be no turbulence such as tends to disturb stratified conditions in day time.

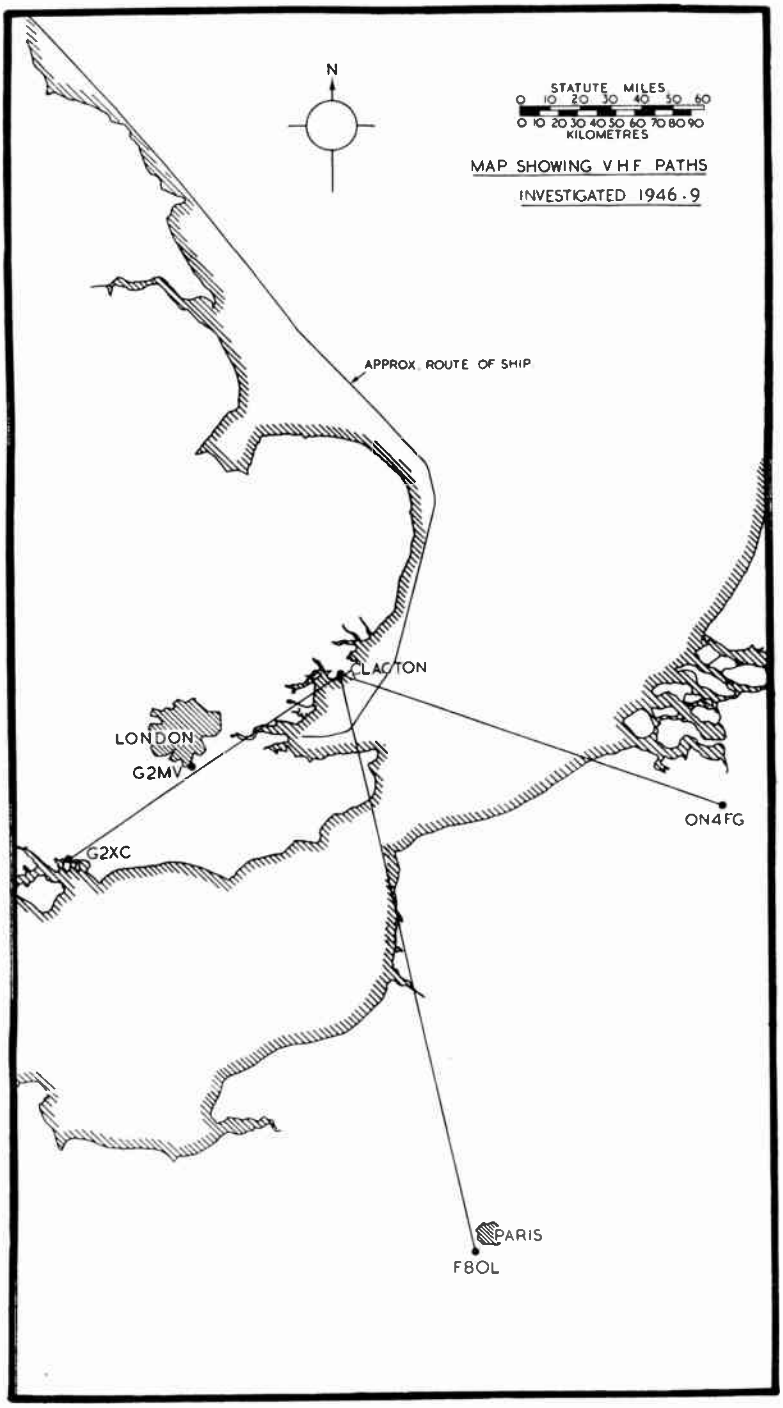

Fig. 4.—Map of V.H.F. paths investigated.

Over sea or water, of course, very little diurnal variation in surface temperature occurs and in this case the weather system prevailing and the sea temperature decide the radio conditions and not the time of day—here again the anticyclone or smaller high-pressure area gives most marked trapping.

Coastal effects often occur which at times bring about a special localized aspect to a circuit which traverses or runs along a coastline. In the main, sea paths investigated by the writer would seem to provide about the same degree of reliability as land paths of similar length.

Unstable cold air, such as gives rise to the building of cumulus or "heap-type" clouds over sun-heated ground, provides poor conditions for radio trapping. The lapse rate of temperature of such air is high. It generally follows in the wake of a depression and often within a day or so the air tends to stabilize again.

Depressions generally bring high winds, overcast, grey, ragged clouds of considerable vertical development and long periods of rain, so that the atmosphere becomes thoroughly mixed and any form of stratification or radio trapping rapidly disappears. It has been noted, however, that occasionally, as the warm front ahead of a depression approaches—(observable as a thin high stratus sheet gradually dropping in height)—some short-lived reflections apparently occur at the front. The height of reflection in such instances would be quite high. The condition soon ceases with the commencement of the rain.

6.0. Results of Practical Tests

In 1938-39 the writer commenced observations and tests in the 40-60 Mc/s region with a view to obtaining further information on tropospheric propagation generally,[4] the implications of which were only just being realized by the scientific world. Unfortunately, the 1939-45 war interrupted the writer's personal work in this field, but the investigation of tropospheric propagation generally received a great impetus, during the war, in many parts of the world, particularly as it affected radar operation. Much has subsequently been published on the results of such tests over various paths,[5] but a considerably greater amount of statistical information in this respect is desirable.

Figs. 4, 5, 6 and 7 provide a selection of records of tests of a qualitative nature, recently carried out from the writer's station, G6DH, at Clacton-on-Sea, and are representative of what may be expected of tropospheric propagation over various paths, distances and frequencies in temperate latitudes.

Fig. 5 shows reception records obtained on a ship, moving up or down the North Sea, of transmissions from G6DH, operating on 145 Mc/s, with 20W output to a four-element horizontal Yagi-type beam 15 m above ground. A similar aerial was used on the ship. The procedure was for the operator on the ship to check the signal for five minutes each hour as the ship progressed up the coast to the Tyne or down to the Thames. The ship covered an average of 10 land miles per hour (16 km).

Unfortunately, owing to various reasons, it was not possible to obtain many complete "runs," but the records obtained serve to show the wide variations in range and signal strength obtained under varying weather conditions. Strengths, whilst only relative, were checked on a meter on the ship receiver.

The optical horizon in these tests would be 35 miles (56 km) approximately. The increases in strength occurring from 40-50 miles (64-80 km) could not be accounted for, but were observed on three occasions.

It will be noted that under good tropospheric conditions the range is effectively extended by four times for the same signal strength. This is typical of the range extension obtained on most paths checked. Peak strengths were of the order

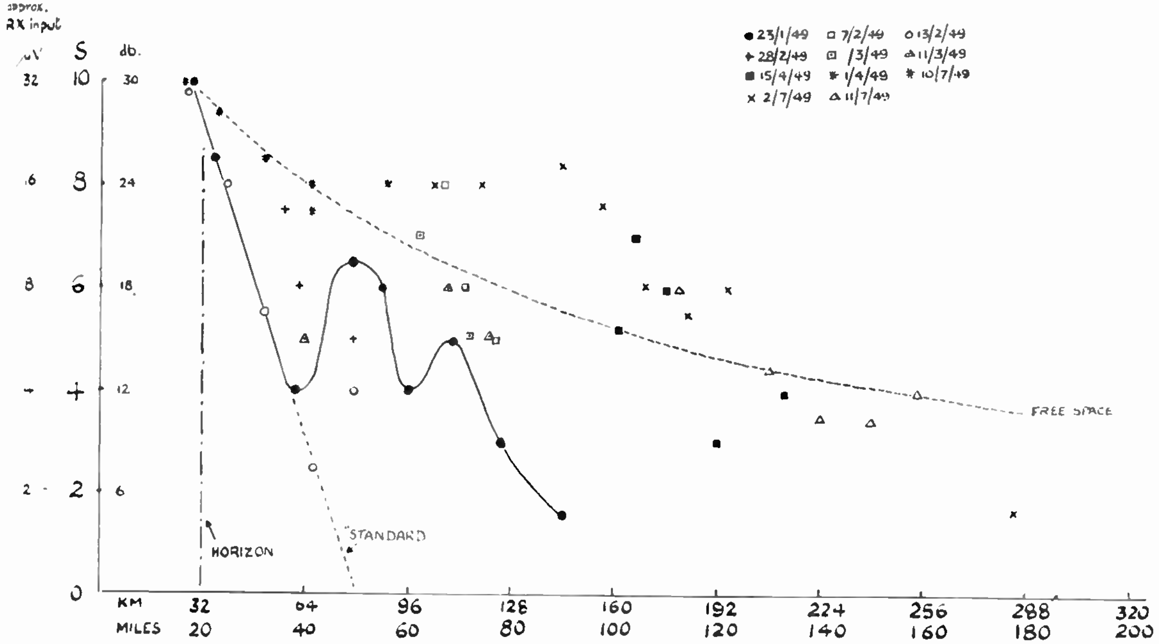

Fig. 5.—Results of tests with ship. The broken line marked "Free Space" indicates attenuation which would be obtained on a free space basis, beyond the radio horizon. The lower broken line shows attenuation expected in a standard atmosphere. Note that recorded results range in the main between these two limits, but at times signals in excess of free space values were recorded.

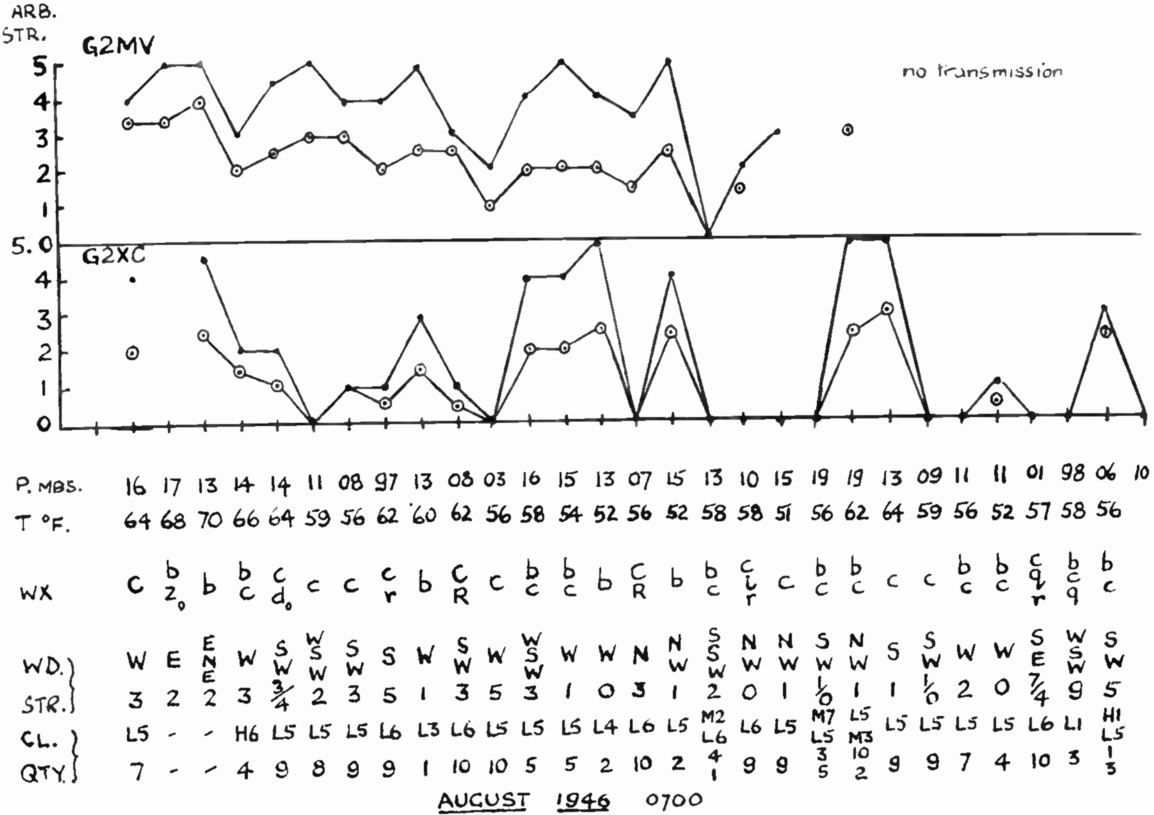

Fig. 6.—Reception records of two stations, on 59 Mc/s, situated in line 112 and 192 km from receiver. The figures, etc., below represent weather records at receiving station (using standard meteorological code). P: pressure in excess of 1000 mbs. T: temperature. WX: weather (C = cloudy, b = blue sky, R = rain, i = intermittent, q = squally. Capitals emphasize condition.) Wind and strength, cloud and quantity are also given. Note: poor reception periods, coincide with rainy or squally weather.

of 6 db. above that expected on a free space attenuation basis (i.e., voltage inversely proportional to distance).

Fig. 6 depicts results of a short series of tests made in August, 1946, on reception of two amateur stations, G2MV and G2XC, operating on 59 Mc/s approximately. These stations were situated 70 and 120 miles (112 and 192 km) respectively from the writer's station and were almost in line so that weather conditions over the first part of the path were the same to the two stations. On no occasions were reflections with skip effect from the further distant station noted, i.e., the nearer station was always of good strength (though not necessarily maximum) if the further distant station was received.

In more recent tests on 145 Mc/s there have, however, been instances of skip effect under certain weather conditions. This skip, though not pronounced, appears to favour distances of the order of 150-200 km, and little or no signal is obtained from stations at intermediate distances of the order of 70-140 km. Under such conditions it would appear that grazing incidence reflection is occurring at an elevated discontinuity and super-refraction is absent or ineffective at the intermediate distances.

Fig. 7 records the results of a series of tests made from November, 1948, to October, 1949, with two amateur stations on the Continent over paths involving considerable distances over sea water. The frequency used was approximately 145 Mc/s.

In the case of ON4FG, Bornhem (nr.

Antwerp), at a distance 205 km, tests were made twice daily at 0745 hours and 1845 hours for 10-minute periods. Relative minimum and maximum strengths are shown. Reception was on a four-element horizontal Yagi 15 m high, and transmission from a 12-element array with 40 W transmitter output.

The tests with F8OL, Meudon (nr. Paris), were at 1930 hours only. Transmission was also on a four-element horizontal Yagi and power 50 W. For comparison the writer also checked the sound signal of the Paris television transmitter on 42 Mc/s.

Both records show the reduced number of path openings during the cold mid-winter period and the maximum trapping occurring in the summer. The rather wide fading range will also be noted. This is typical of tropospheric propagation generally, where multi-path interference effects and minor short period weather variations cause considerable fading—often of the order of 20 db. from maximum to minimum signal. The fading

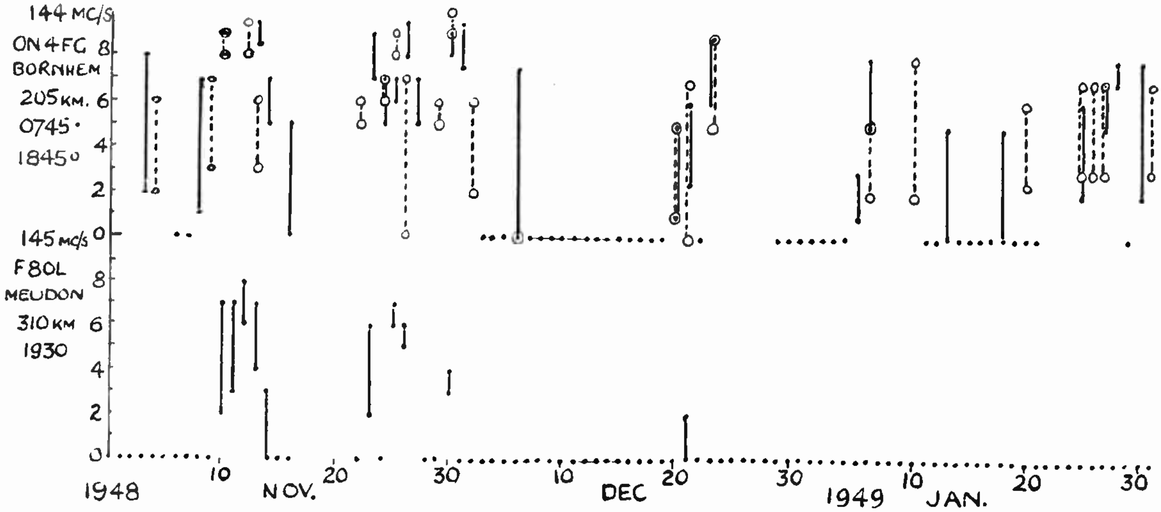

Fig. 7 (*a*).

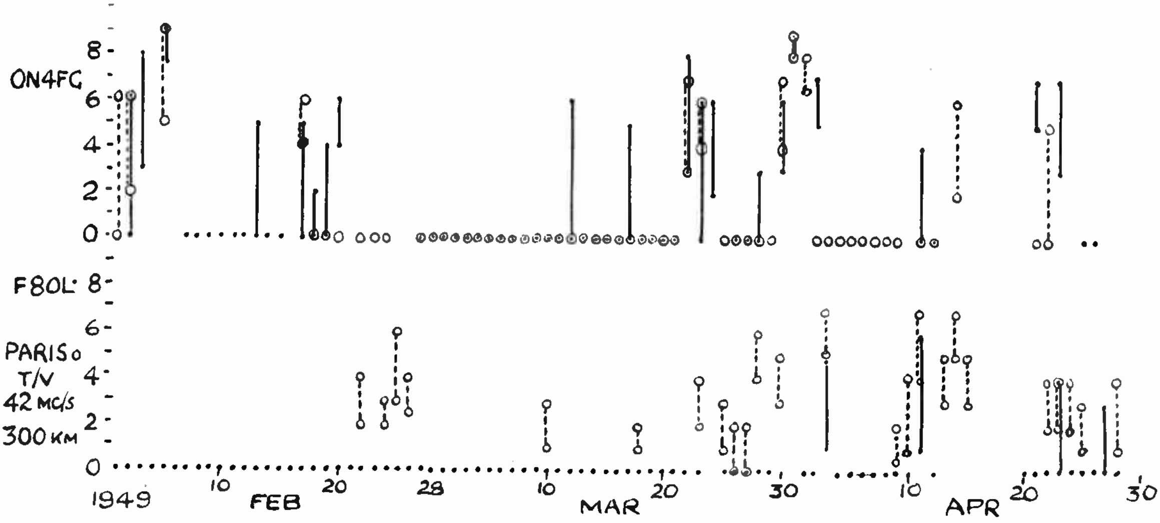

Fig. 7 (*b*).—*See following page.*

NOTE.—Points marked on base line indicate *no* signal received. Blank space indicates no record.

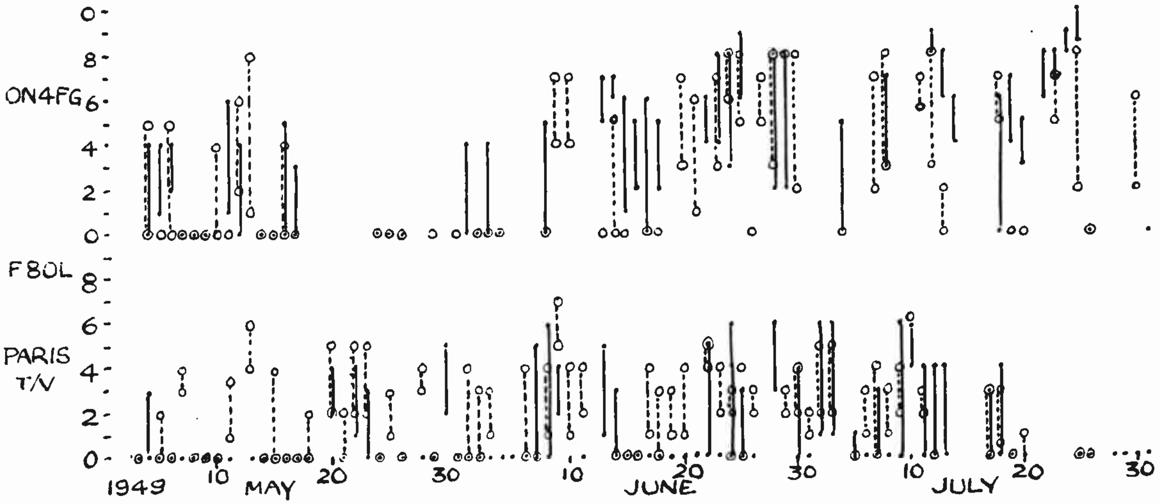

Fig. 7 (c).

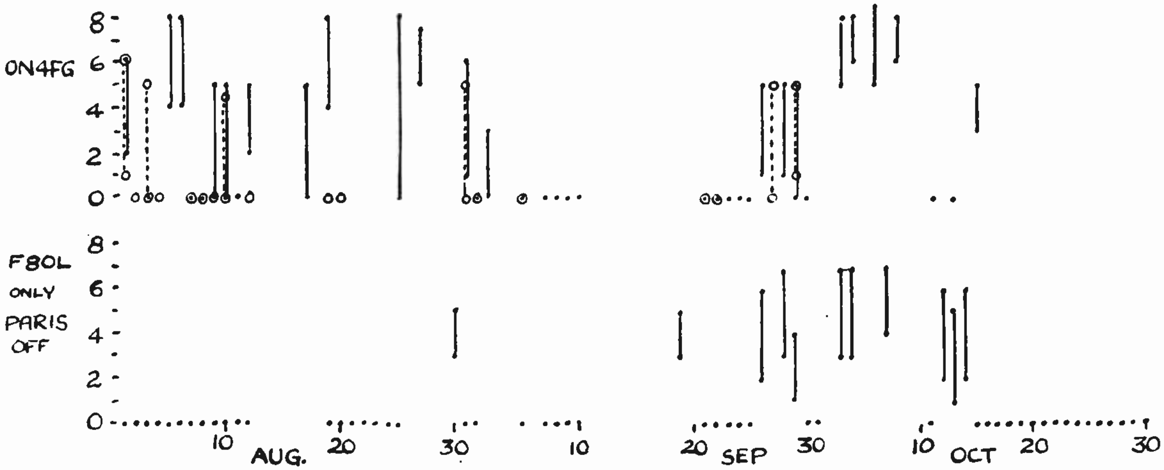

Fig. 7 (d).

Fig. 7 (*a*), (*b*), (*c*) *and* (*d*).—*Results of one year's observations on three continental stations, as received in S.E. England. Note normal improvement during summer months and almost nil reception during mid-winter from* **F8OL**. *Arbitrary strengths only are indicated and range of fading from peak to minimum over* 10-*minute periods. Approximate scale is* 3 *db per " S " point. Records of Paris television transmitter were only available for part of the year.*

period is normally rather longer (i.e., sometimes several minutes) than that obtained in ionospheric propagation, but rapid fading is occasionally observed.

Only under fine or anticyclonic weather conditions were the further distant F8OL signals audible.

Normally the Paris signal on 42 Mc/s had to reach a certain level before the 145 Mc/s signal was audible. Only on two occasions during the whole year was the 145 Mc/s signal audible when the 42 Mc/s signal was not.

6.1. *Polarization*

According to some careful tests made by American amateurs[6] little or no difference has been observed in the ranges obtained, fading, etc., when using horizontally or vertically polarized aerials. For any particular set of conditions on a short-term basis, one or the other polarization may be found to give maximum field strength,

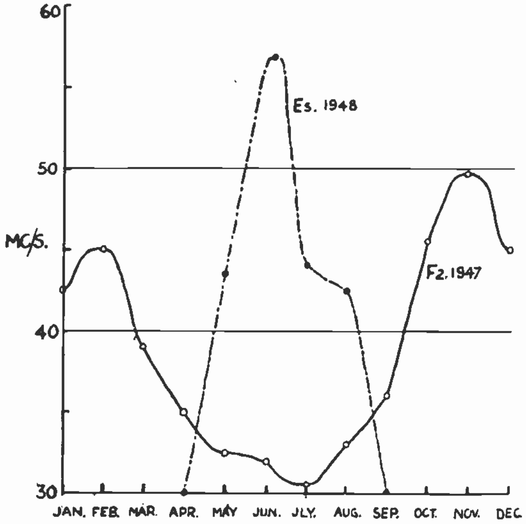

Fig. 8.—Seasonal variations in F_2 and E_s M.U.F.s at sunspot maximum years.

but on a long-term basis and speaking generally, the above conclusion would appear correct.

7.0. Ionospheric Propagation

As in the case of extended range by tropospheric propagation, owing to the comparative unreliability of ionosphere reflected signals, the main consideration will be that of avoiding interference with local services by long-distance stations.

It is, of course, usual to refer to the maximum frequencies reflected by the ionosphere as "critical" (fE_s or fF_2) for normal incidence or maximum usable (M.U.F.) for oblique incidence. Critical frequencies are those measured by ionosphere sounding stations. M.U.F.s are seldom "measured," but by observing the reception of certain suitably located stations in the 30-50 Mc/s band it is possible to estimate M.U.F. quite closely. Knowing the critical frequency of a layer the M.U.F. at that point can be obtained by multiplying the critical frequency by the M.U.F. factor.

At frequencies over 30 Mc/s only in the sporadic E (E_s) and F_2 layers of the ionosphere, at heights of the order of 120 km and 300 km respectively, will the ionization at times be sufficiently great to bring about reflection of waves at oblique incidence.

Because solar radiation is the main ionizing agent both of these regions are only effective during daylight or twilight hours on the frequencies being considered (except for occasional E_s reflections during night time; see later reference).

In temperate latitudes in either hemisphere the two layers reach maximum ionization at different times of the year, the E_s during summer and the F_2 in winter. Thus in summer frequencies over 30 Mc/s are chiefly reflected by sporadic E and in winter by F_2 layers. Fig. 8 illustrates this characteristic for years of maximum sunspot activity. During the years of minimum activity in the solar 11-year cycle the M.U.F.s are considerably lower and there is less difference between winter and summer F_2 M.U.F.s. It will be noted that the F_2 layer has in fact, two peaks a month or so either side of mid-winter, this being normally the case.

The position in the equatorial and tropical zones is somewhat different, there being less change in the layers through the year. E_s M.U.F.'s peak in the equatorial regions, while the F_2 layer has its maximum frequencies in the 20 deg. latitudes north and south of the equator, with a drop over the equator.

Fig. 9 shows the general form of distribution of F_2 M.U.F. on a world-wide basis for November, 1947, a year of maximum sunspot activity. On individual days the M.U.F. may peak 15 per cent. or even higher than the values shown and the distribution of ionization undergoes day-to-day variations so that the M.U.F. map may at times look very different.

Fig. 10 indicates very roughly the distribution of E_s on a similar basis. This distribution is subject to very great day-to-day variations and, in fact, insufficient data are yet available to provide accurate prediction in regard to E_s.

8.0. Distances Covered

Unlike tropospheric propagated waves those reflected by both E_s and F_2 layers show quite distinct skip zones. The skipped distances depend, of course, on the layer heights and the transmitted frequencies, but the distances involved over 30 Mc/s are seldom less than 800 km (500 miles) for E_s and 1600 km (1,000 miles) for F_2 reflections. When the frequency in use approaches the M.U.F. so that only a grazing incidence signal is reflected, the distances covered become about 2,000 km by E_s and 5,000 km by F_2. These distances represent the greatest covered by single hops.

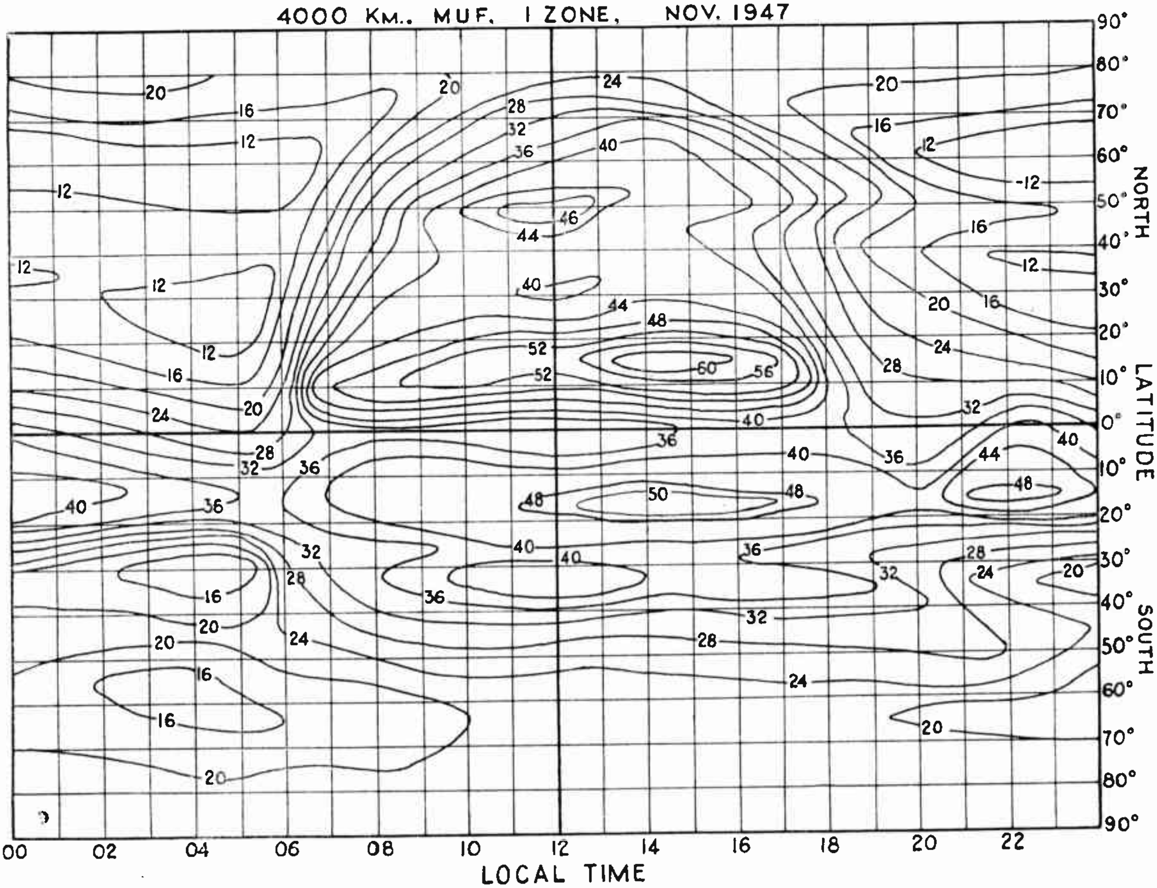

Fig. 9.—Median F_2 4,000 km M.U.F. world distribution chart (after D.S.I.R. and C.R.P.L.) for sunspot maximum year.

As double-hop reflections by E_s are very unusual, chiefly by virtue of the localized nature of E_s " clouds " of high ionization, especially in temperate latitudes, we may say that effective ranges covered by E_s reflections are 800-2,000 km (500-1,250 miles).

Whilst multi-hop F_2 reflections occasionally occur to distances exceeding 8,000 km, even on frequencies up to 50 Mc/s, the signal strengths are low in view of the distances involved and duration of path opening short, so that here again it may be said that only the single hop reflections are important.

Thus the effective range covered by F_2 reflections (on frequencies over 30 Mc/s) is 1,600-5,000 km (1,000-3,100 miles).

9.0. Frequency Limits

As is now well known the M.U.F.s or critical frequencies of the ionosphere follow the smoothed sunspot number. Experience through the last sunspot maximum has shown that, in temperate latitudes, the F_2 layer seldom, if ever, reflects frequencies higher than 52 Mc/s. In the tropics this figure may rise to 60 Mc/s, but little or no evidence, of a practical nature, is available in this respect.

In the case of E_s, frequency limits are considerably higher and may for short periods reach as high as 100 Mc/s in tropical or subtropical latitudes. In temperate latitudes, however, E_s reflection in excess of 70 Mc/s is very rare and may be considered negligible. As the

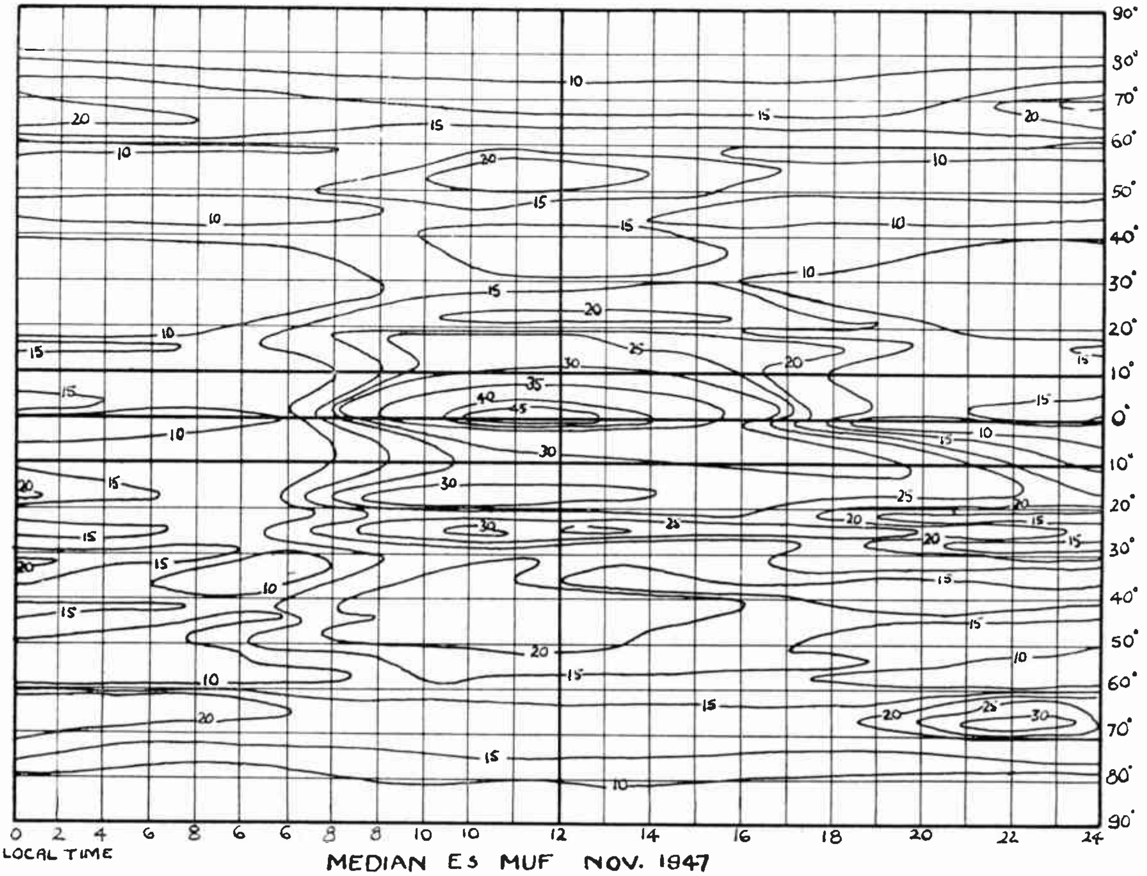

Fig. 10.—*World distribution of* E_s *M.U.F.—very approximate.*

frequency is reduced below 60 Mc/s E_s reflections become more frequent and of longer duration.

10.0. Daily and Seasonal Variation of Ionospheric Characteristics

Fig. 11 indicates the time/frequency characteristic of the F_2 layer on a typical day at sunspot maximum.

Considerable day-to-day variation may occur both in time of peak frequency and actual frequency limit. The times of rise in M.U.F. after dawn or the fall at sunset may be staggered ±one hour on consecutive days. Further data in this respect on a world-wide basis are, of course, available in the prediction charts and records issued by various authorities, including the D.S.I.R. in this country and the C.R.P.L. in U.S.A.[7]

From these data it will be evident that (particularly for paths well removed from the auroral zones) the first 10 Mc/s of the frequency band we are considering, i.e., from 30-40 Mc/s, may provide relatively reliable long distance communication channels for a few hours during day-time.

Owing to its purely sporadic nature, E_s occurrence is subject to great hour-to-hour and day-to-day variation, hence a rather different method is adopted in showing records of E_s duration. Figs. 12 (*a*), (*b*) and (*c*) are actual records of E_s reflections, of 40 Mc/s or higher, at oblique incidence, occurring in Europe for the summers of 1947, 1948 and 1949. In the case of Fig. 12 (*b*) the readings of fE_s taken by the Slough ionosphere sounding station are included for comparison purposes. These records represent a collation of all E_s reflections from known stations in Europe within a radius of 2,000 km, from Scandinavia to Spain and N. Africa, as received in S.E. England. Owing to the localized nature of the E_s clouds only at times is there correlation with the Slough soundings.

Whilst there is some controversy as to whether or not E_s, like F_2, peaks with the sunspot cycle, in the writer's experience the actual E_s M.U.F.s *are* higher at sunspot maximum though the frequency of E_s occurrence on *lower* frequencies is not necessarily less at sunspot minimum.

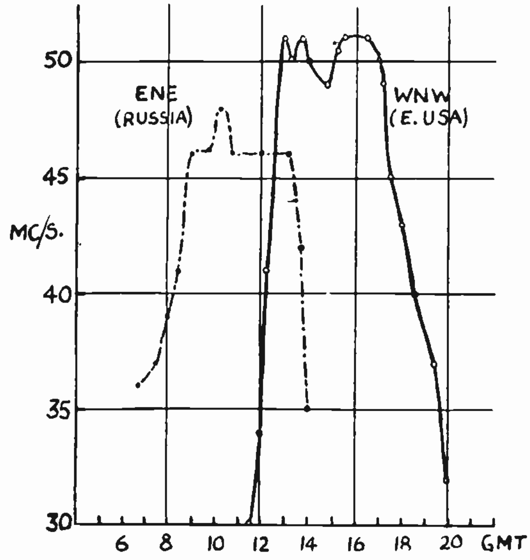

Fig. 11.—Typical F_2 M.U.F. characteristic for a day at sunspot maximum for two paths from S.E. England. Considerable day-to-day variation occurs.

11.0. Further E_s Characteristics

The subject of sporadic E ionization is one that has given lead to much discussion and conjecture. The actual agent or agents causing the intense ionization are not definitely identified at the present time. There appear to be two or more types of E_s ionization, in particular the " temperate " and auroral types.

In temperate or tropical latitudes south of 55 deg. in N. hemisphere or north of 55 deg. in S. hemisphere, there seems little doubt to the writer that direct solar radiation is the main factor because the E_s occurrence is almost entirely limited to day-time hours (refer to Fig. 12). Some authorities, however, claim meteor showers to be the causative agent.

If the regions of maximum E_s ionization are carefully plotted, by repeated checks on reflected signals, it is noted that these clouds drift, often at quite high speeds, in a random fashion. Were the ionization purely due to solar illumination one would expect to find an east-west apparent drift through the day. For this reason it appears that another factor is operating in addition to solar radiation. Possible suggestions are (1) that a condition of the upper atmosphere is necessary for E_s ionization to occur under solar illumination or (2) that the solar radiation is of ray type, the intensity of which fluctuates over a small area.

Fig. 13 illustrates the preponderance of E_s in southerly directions as recorded in S.E. England. Reception has been classified into three main zones, N.E. (from Scandinavia, etc.), E.-S.E., Central Europe and South, from S. France, N. Africa, etc. Points of reflection would be located on an arc of radius of the order of 700 km from S.E. England.

Fig. 14 shows a comparison for June, 1948, on a local mean time basis of daily E_s oblique incidence duration in Europe, over 40 Mc/s, and Eastern U.S.A. over 50 Mc/s (these being the nearest figures available). It is interesting to note that there is reasonably good correlation. Sixty-eight per cent. of the European occurrences were repeated five or six hours later by similar openings in U.S.A. and 83 per cent. of the American occurrences correlated with those in Europe.

The correlation is not so good if the results of only two ionosphere sounding stations, Slough and Washington, are compared, as is to be expected if the writer's previous suggestions are correct.

It might be mentioned that E_s occurrence has been noted to be more frequent and recorded M.U.F.s higher during the passage of active sunspot groups.

In the auroral zones, and north of 55 deg. latitudes there is an increasing tendency with progress nearer the poles for daytime E_s to be less and for night-time E_s to increase. Stations in the 60 deg.-70 deg. latitudes record highest E_s in the midnight and early hours, though the values recorded are seldom as high as day-time values for temperate latitudes.

At times of ionosphere disturbance this auroral type E_s is observed further south and reflections noted on frequencies as high as 60 Mc/s, well after sunset in southern England. Such auroral

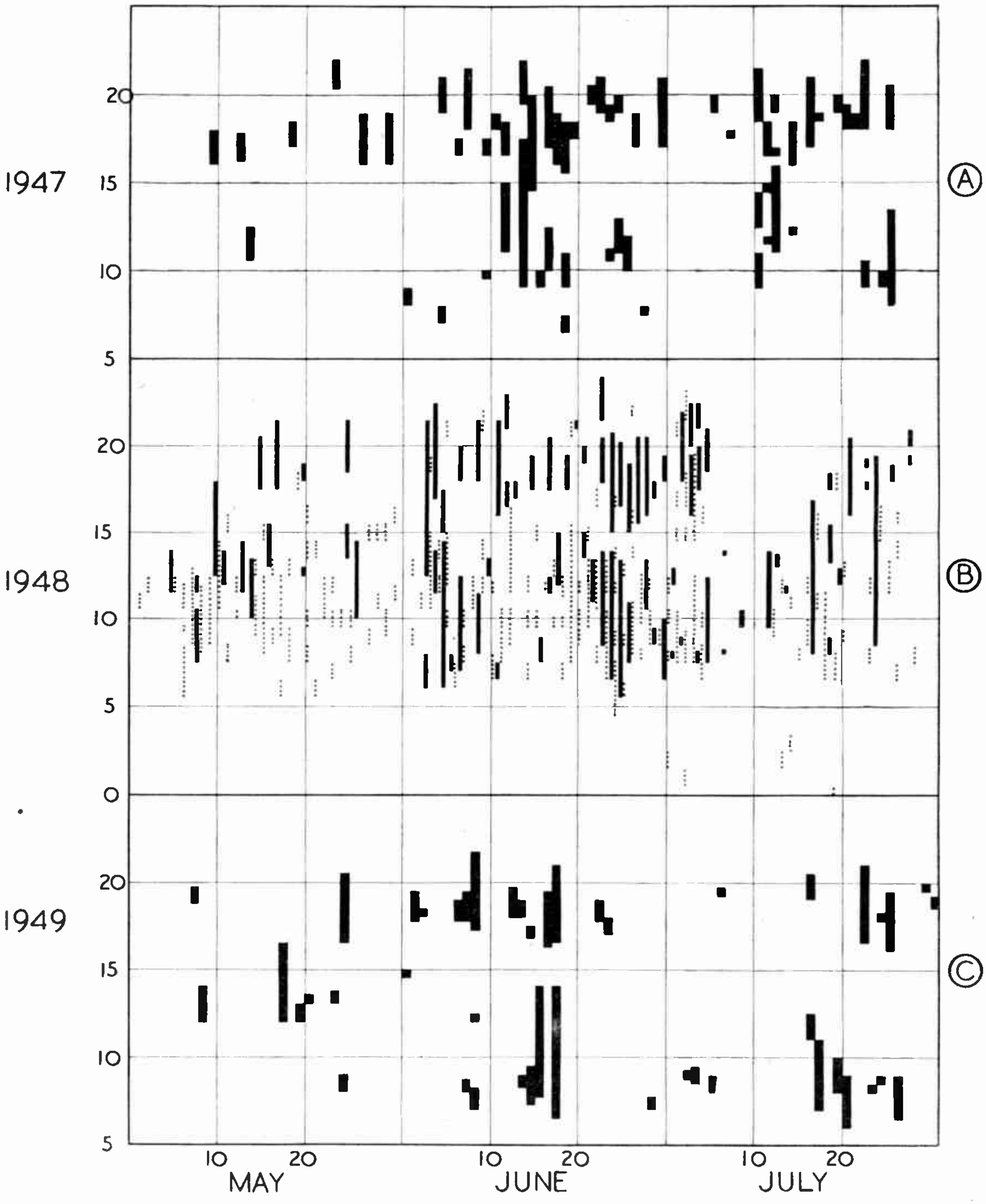

Fig. 12.—Duration of E_s reflections exceeding 40 Mc/s from Europe as received in S.E. England, in summer, for three years at sunspot maximum. (b) compares Slough ionosphere soundings where 8 Mc/s or greater was recorded at vertical incidence.

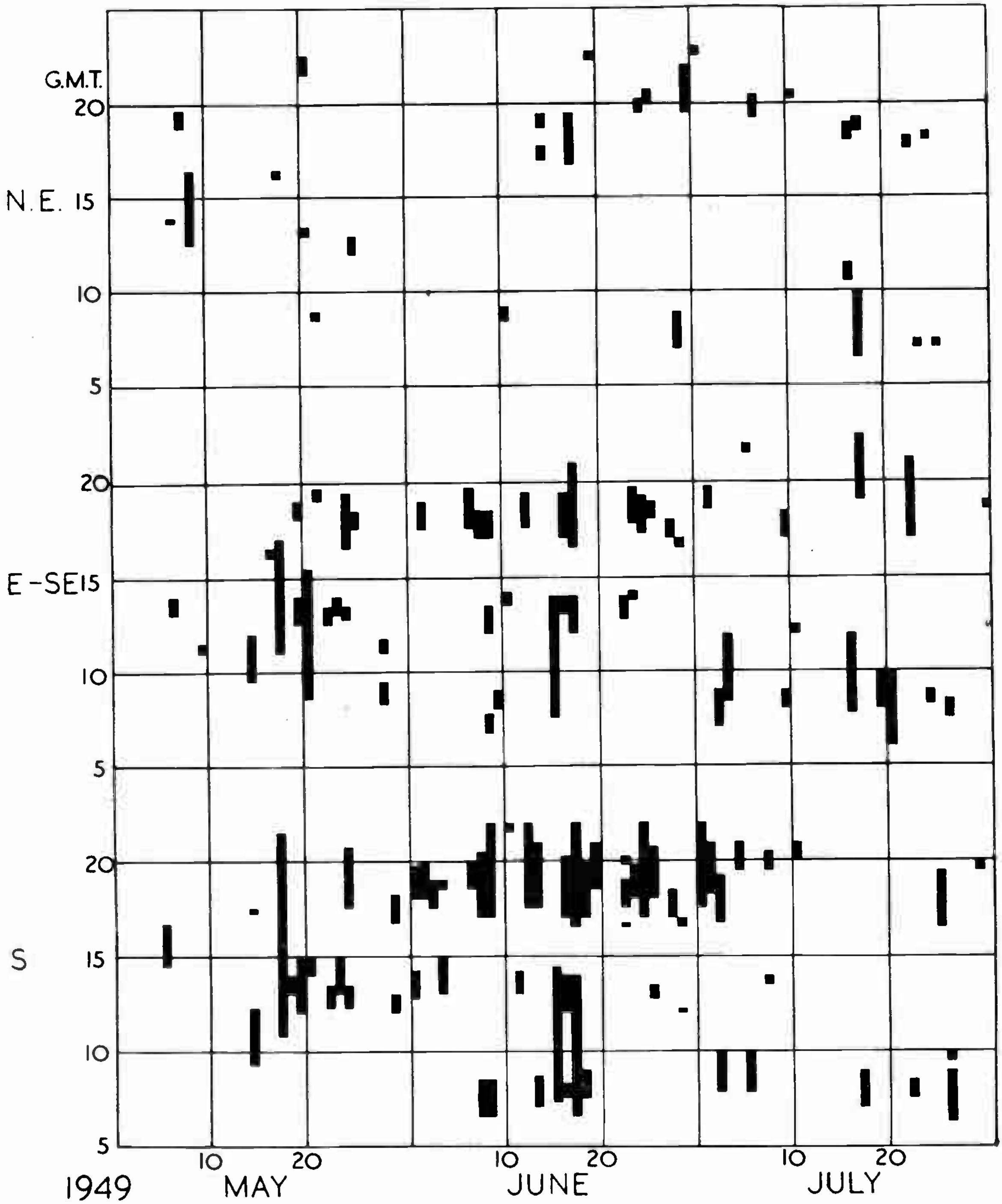

Fig. 13.—E$_s$ occurrence for three bearings from S.E. England. Note preponderance to South.

E_s seldom appears to be horizontally stratified so as to be suitable for normal radio reflection, but on rare occasions this is noted, both in Europe and U.S.A. Under such conditions in England, signals in the 40-50 Mc/s region are received from N. Europe. The duration of such occurrence is normally limited to an hour or two, possibly on three or four days per year.

A more usual type of auroral reflection occurring during ionosphere storms is that due probably to poorly defined auroral ionization of vertical or semi-vertical orientation. Under such conditions rather poor and very fluctuating reflections on frequencies up to the 100 Mc/s region (with a typical auroral flutter fading) may be obtained by aiming beam aerials of both receiving and transmitting stations towards the auroral curtain (generally N.-N.W. in the northern hemisphere).

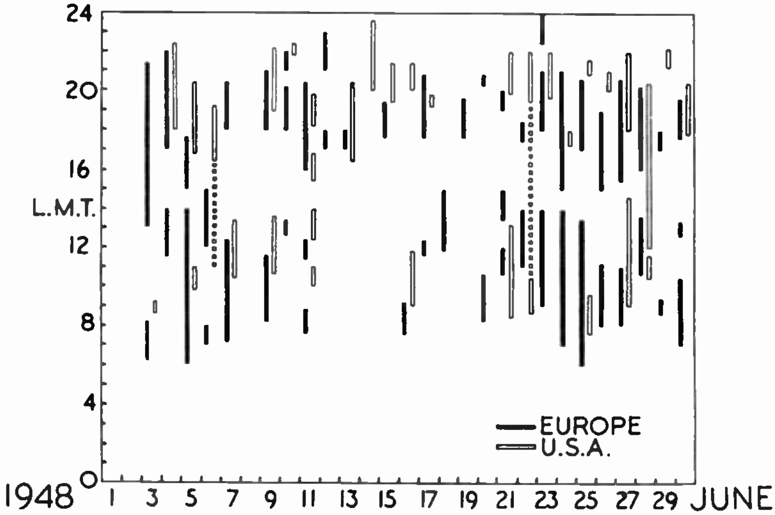

Fig. 14.—Comparison of U.S.A. and European E_s occurrence on a local mean time basis. There is frequent correlation, within one hour, although the actual durations of individual " openings " show wide variations.

12.0. References

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APPENDIX

Refraction: Application of Snell's Law to Curved Earth and Derivation of " M."

Snell's Law of refraction may be expressed as

$$n_0 \sin \beta_0 = n_1 \sin \beta_1$$

where n_0 and n_1 are the refractive indices of two adjacent mediums (Fig. 15*a*) and β_0 and β_1 are the angles of incidence and refraction.

Taking, for convenience, the angles α_0 and α_1 between the ray and the boundary surface the relation now becomes:

$$n_0 \cos \alpha_0 = n_1 \cos \alpha_1$$

If there are several boundaries (Fig. 15*b*) then

$$n_0 \cos \alpha_0 = n_1 \cos \alpha_1 = n_2 \cos \alpha_2, \text{ etc.}$$

and for a continuously variable medium

$$n \cos \alpha = n_0 \cos \alpha_0$$

where n and α are functions of height and the index $_0$ indicates a reference level.

In the case of the earth and its atmosphere the surfaces of constant n are not planes but are

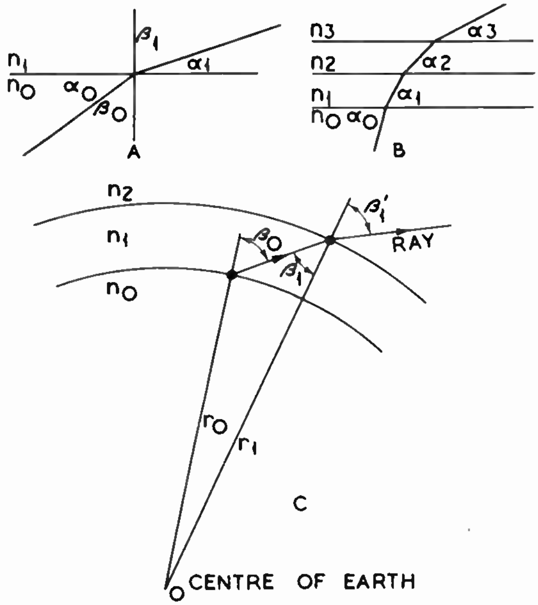

Fig. 15.—*Application of Snell's Law for curved earth.*

concentric spheres about the earth's centre.

From the triangle 0 . r_0 . r_1 (Fig. 15 (*c*))

$$\frac{\sin \beta'_0}{r_1} = \frac{\sin \beta_1}{r_0} \quad [\sin \beta'_0 = \sin (180° - \beta_0)]$$

and similarly

$$\frac{\sin \beta'_1}{r_2} = \frac{\sin \beta_2}{r_1} \text{ etc.}$$

thus

$r_0 \sin \beta'_0 = r_1 \sin \beta_1$ and $r_1 \sin \beta'_1 = r_2 \sin \beta_2$, etc.,

also (from Snell's law) $\sin \beta'_1 = \frac{n_1}{n_2} \sin \beta_1$

and substituting $r_1 \frac{n_1}{n_2} \sin \beta_1 = r_2 \sin \beta_2$

or $n_1\, r_1 \sin \beta_1 = n_2\, r_2 \sin \beta_2$ and similarly $=$ $n_3\, r_3 \sin \beta_3$, etc., or introducing α with the horizontal and generalizing for a continuously variable medium

$$nr \cos \alpha = n_0\, r_0 \cos \alpha_0 \dots\dots\dots\dots\dots\dots (1)$$

r_0 may be any convenient reference level, say a for the earth's surface or $a + h_1$ allowing h_1 for the transmitter height.

If h = height above ground so that $r = h + a$ the above equation may be written :

$$n\,(h + a) \cos \alpha = n_0\, a \cos \alpha_0$$

$$\text{and } n\left(\frac{h}{a} + 1\right) \cos \alpha = n_0 \cos \alpha_0$$

As $\frac{h}{a}$ is a very small quantity and n is only very slightly greater than unity, $n\left(1 + \frac{h}{a}\right)$ may be written $n + \frac{}{a}$ with negligible error. This quantity $n + \frac{h}{a}$ is called the modified refractive index and equation (1) can then be written

$$\left(n + \frac{h}{a}\right) \cos \alpha = n_0 \cos \sigma_0$$

Instead of $n + \frac{h}{a}$ the symbol M is used such that

$$\mathrm{M} = \left(n + \frac{h}{a} - 1\right) 10^6$$

HONORARY LOCAL SECTION SECRETARIES

MERSEYSIDE SECTION

Joe Gledhill was born at Wakefield, Yorks, in July, 1916. He obtained a major scholarship and studied physics at Leeds University, qualifying for his degree in 1938. He has since obtained the final certificates of the City and Guilds in Radio Communications and Telephony.

Mr. Gledhill received his early training as a post-graduate apprentice with the Automatic Telephone and Electric Company Ltd. and in 1941 he joined the inspection department of that company. He was appointed as a development engineer in the carrier and transmission equipment laboratory and is now a Senior Development Engineer in that laboratory.

Elected an Associate Member in December, 1946, Mr. Gledhill was appointed the Honorary Local Secretary for the Merseyside Section on its formation in 1947. The success of this Section has been largely due to his efforts and organization.

WEST MIDLANDS SECTION

Robert Alfred Lampitt was born at Wolverhampton in March, 1916. He received his technical education at the Wolverhampton and Staffordshire Technical College, obtaining a National Certificate in Electrical Engineering and City and Guilds Radio Communication certificates; he completed the Graduateship Examination in May, 1944.

After his initial training he was a full-time lecturer in radio theory at the Wolverhampton and Staffordshire Technical College from 1941 to 1942, continuing as part-time lecturer in communications engineering until the present. Mr. Lampitt then joined the Radio Gramophone Development Co., Ltd., as a test engineer and transferred to the laboratory as a development engineer in 1943. He is now Chief Engineer of the Radio section of the Ever Ready Co. (G.B.), Ltd., at Wolverhampton.

Elected a student member in September, 1943, Mr. Lampitt qualified for transfer to Associateship in September, 1944. He was elected an Associate Member in March, 1946.

Mr. Lampitt was appointed Honorary Local Secretary for the West Midlands Section in July, 1948.

SOUTH MIDLANDS SECTION

Clarence Stokes, born in London in 1909, was educated at Bablake School, Coventry, and, studying at the Coventry and Birmingham Technical Colleges, took a degree in Physics in 1933 and an honours degree in Electrical Engineering recently. He is an Associate Member of the Institutions of Electrical and Mechanical Engineers.

He served an apprenticeship with the British Thomson-Houston Co. until 1932 and was then appointed design engineer with that Company. In 1936 Mr. Stokes joined the staff of the Coventry Technical College as full-time lecturer in the Electrical Engineering and Physics Department, and since 1942 has been responsible for the electronics and telecommunications work of that department.

Mr. Stokes became an Associate Member of the Institution in 1943 and transferred to full membership in 1948. He was appointed Honorary Local Secretary for the South Midlands Section in 1946.

JOURNAL OF THE BRITISH INSTITUTION OF RADIO ENGINEERS

PULSE NAVIGATION SYSTEMS*

by

W. L. Barrow†

SUMMARY

A variety of systems for navigation based on pulsed radio transmission have developed during and since World War II. In this paper a brief review of pulse navigation systems is presented, together with a discussion of the most significant scientific and engineering factors that influence the suitability of such systems for marine navigation.

1.0. Basic Ideas

The basis of all so-called " pulse navigation systems " is the *time* required for a pulse of radio frequency energy to traverse a given distance. This principle is utilized for navigation and position finding in three general methods.‡

In the first method, which will be called the " circular " method, a train of pulses of radio energy is radiated by a transmitter at the unknown position. Some of this energy is returned from a reflecting object or from a radar transponder at a known position, and the time for the round trip is measured. The distance between the points of transmission and reflection is in the simple case directly proportional to the time required for the round trip. To determine the unknown position, the distances to two known reference points are measured, and position is found as the intersection of two circles, drawn on a conventional chart with centres at the two points of reflection and with radii equal to the two respective measured distances.

In the second method, which is nothing more than conventional radar, the pulses are radiated in a narrow beam, by means of a directive antenna, and the unknown position relative to the reflecting object is determined from the bearing of the beam and the indicated distance. The first method may also be carried out with conventional radar, although it may be separately instrumented also.

The third method of determining position by radio pulses will be termed the " hyperbolic " method. In it, pulses are radiated simultaneously§ from transmitters at two known ground positions and are received by equipment at the unknown position. When the unknown position is closer to one transmitter than to the other, the pulses from the nearer transmitter are of course received before those from the more distant one. A comparison of the two received pulse trains gives the time difference of arrival, which is proportional to the difference in distances to the two known positions. A curve may be drawn on the chart of the region such that every point on the curve is closer to the one transmitter location than to that of the other by the same measured amount. This curve is a line of position characterized by the measured time difference. The receiver lies somewhere on this curve. A similar measurement from another pair of transmitters, one of which may coincide with one of the first pair, determines a second line of position and its intersection with the first fixes the geographic position of the receiver. Geometrically the lines of position form hyperbolic curves having the two known transmitter locations as foci. Each transmitter pair establishes a family of hyperbolic curves which may be plotted on the chart and used for navigation in a manner quite similar to curves of latitude and longitude. Naturally, positions in terms of latitude and longitude may be readily determined from the chart also.

It might appear that circular and straight radar methods provide a simpler procedure for the navigator, because it might seem that ship's own position may be plotted readily on a conventional chart, whereas hyperbolic methods require

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* Reprinted from the *Proc.I.R.E.* (*Aust.*), October, 1949.

U.D.C. number 621.396.663 : 621.396.933.1.

† Sperry Gyroscope Company, Inc.

‡ A fourth method, using two bearings, will not be discussed here.

§ In actual systems, the pulse train from one station, the " slave," has a constant delay with respect to the pulse train from the other, or " master " station.

special charts or more elaborate computation. This is not the case in practice, however, for two reasons. Firstly, it is not an altogether simple matter to accurately plot large distances on charts because the curvature of the earth must be taken into account. Secondly, the work of making the hyperbolic charts, although great, has already been done for most of the regions covered and once done reduces the determination of an individual fix by a navigator to a very simple matter indeed.

Of the three methods of electronic navigation, the hyperbolic method alone has the feature that the ship radiates no transmissions and operates entirely as a silent listener with only a receiver for equipment. Although co-operation between the ground stations is necessary, their radiations go out like light from lighthouses to be used independently and without interference by all who are within range. This is an important feature, for there is no practical limit or saturation to the service that can be rendered, as in the case with other methods. In the circular methods, mutual interference is generally expected to place a limit often to twenty simultaneous users of a given system and region.

It is interesting to note that, except for conventional radar, a minimum of three transmitting stations is always required to determine a position fix. In the circular systems, at least two land stations and one ship station are necessary. In the hyperbolic systems at least three land-based transmitters are required and only a receiver is needed aboard ship.

An important practical aspect of electronic navigation systems results from the fact that their reference points are terrestrial, and therefore observations make no use of sidereal time information and are independent of it. It is thus a simple matter in most systems, particularly hyperbolic ones, to preset the adjustments of the equipment to correspond to a desired future position and to use the indication of error as an aid to steering or to set the course in a predetermined manner. As the desired future position is approached, no matter what the speed or time of day, the observations will get closer and closer to those preset in the equipment, finally coinciding upon arrival at the specified position.

2.0. Useful Distance

Of greatest importance in any consideration of electronic navigational aids is the maximum distance or coverage that may be provided by the system under practical operating conditions. Although the determination of maximum distance for a particular system can only be found accurately from operating field experience in which the effect of field and shipboard maintenance and operation of all parts of the system are inherently included, general trends and approximate values may be obtained from a study of the individual factors. These factors involve well-known facts and principles of wave propagation and electrical communication, but they are nevertheless worth some elaboration here as applied to pulse navigation systems.

Radio energy may be transmitted from one point on the earth's surface to another, depending on the carrier frequency, the power and the distance, by one or more types of waves or over one or more separate paths, as follows : (1) the " direct wave," which occurs mostly with microwaves and corresponds to the ray of a searchlight ; (2) the " ground wave," which is a wave slidingly attached to the earth's surface ; and (3) the " sky wave," which is a wave that is bent by the ionized layer or ionosphere and returned to the earth via the sky with one or more successive reflections between earth and ionosphere.

Conventional radar operates almost exclusively by means of direct waves, as do certain other navigational systems, and they are thus limited substantially to line-of-sight distances. This limitation is fully compatible with the application to impending-collision warning, inshore, coastal, lake and river navigation, and harbour traffic control, and it is mainly in this short-distance application that radar *per se* will find use. Direct wave propagation at micro-wavelengths is affected by certain atmospheric conditions, such as snow, sleet and heavy rain, the influence being greater for the very short wavelengths. It is, in fact, possible to locate storm and hurricane centres with radar. Experience thus far has nevertheless shown that marine radar can see through bad weather of all kinds with adequate vision for short-distance navigation.

Ground wave transmission is employed in the Loran systems, which are well designed to take advantage of the reliability of this mode of propagation (Loran may also operate with sky waves). The rate at which the strength of ground waves is reduced with distance depends on the electromagnetic characteristics of the earth, in our case sea water, lake or river water, the spreading of the energy over an ever-increasing volume in its outward motion, and the bending of the waves around the spherical surface of the earth. Although the mathematical relations between signal intensity and distance are very involved, the maximum distance obtainable is generally greater for greater wavelengths, other factors being equal. At the medium wavelengths, the distance covered by the ground wave is considerable. For example, with peak powers of 100 kW at wavelengths around 150 m distances of 500 to 700 nautical miles are reported. The increase of ground wave distance with wavelengths has led to investigations of the possibilities of very long wavelengths in "Low Frequency Loran," in which propagation characteristics should enable the daytime distance to be increased by a factor of two or more. The evaluation of these very long wavelengths cannot yet be said to be complete, as some other factors mitigate against an overall improvement.

Another major factor in determining distance of pulse navigation systems is the presence of atmospheric and other radio noise. Atmospheric noise is stronger at the longer wavelengths and it also varies geographically and with weather, being far worse in tropical latitudes than in more northerly ones and also during storms, sleet, and snow. Although pulse navigation systems that employ visual indication have tremendous advantages over communication and other systems using aural indication and can generally be expected to perform better under adverse noise conditions, the maximum range is nevertheless reduced at longer wavelengths by this factor.

The problem of transmitter antenna design may be of great significance. At wavelengths of micro to short values, antennas of high efficiency are physically realizable and economical, and even for the medium wave-length of conventional Loran efficient antennas can be readily constructed. For appreciably longer waves the size required to yield an efficient radiator becomes almost prohibitive, and when very long waves are used with heights that are for them much too small, the efficiency is unavoidably poor. Because of the practical limitations of antenna design the radiation resistance is low compared to the ohmic resistance and the reactive component of its impedance is high. This situation causes high power loss both in the antenna and in associated coupling circuits. To overcome this difficulty, relatively great power is required in the transmitter equipment.

For a limited range of distances beyond a value that depends on a number of factors, including those described above, the intensity of the ground wave will be reduced and that of the sky wave may be increased in such relative proportions that an interference of the received ground and sky wave pulses exists and one cannot be clearly separated from the other. This region of interference will, in certain cases, be the factor that limits the maximum usable distance for ground wave operation, even though the intensity of the ground wave in the absence of interference might permit satisfactory operation. Pulse systems have a great advantage over continuous wave systems in this regard, since pulsed techniques provide a means for separating the two waves.

Navigation by sky wave transmission becomes practical when an adequate sky wave is returned and when either the ground wave is absent or the path followed by the sky wave in its excursion through the ionosphere is long enough to permit its separation from the ground wave on the indicator. There are a number of reflecting ionized layers whose ability to return a wave to the earth depends on their state of ionization, which in turn varies with sun position, sun spots, and other corpuscular and radiation phenomena.

The intensity of the sky wave generally varies with time or fades because the net wave received may be the sum of several parts, each travelling different lengths and having different reductions in intensity both of which are continually changing. Reflection also varies significantly with wavelength. For practical purposes at medium wavelengths, waves are reflected only at night, so that sky wave operation must be restricted approximately to the hours between sunset and sunrise over the transmission path. During the night period ground wave transmission at medium wavelengths suffers a reduction in distance because of increased atmospheric noise. Since the reduction in intensity of the sky wave with distance is not very rapid, this mode of operation provides the greater distance of the two and is thoroughly practical for navigational use. Instead of 500 to 700 miles cited in the preceding example, the reliable night time wave transmission distance is quoted as about 1,400 miles.

The arrival of one or more sky waves at the receiver has proved to be a fortunate thing in pulse navigation systems. Since the energy is transmitted in short discreet bursts and the indicator spreads out the successive pulses that arrive over paths of different time delay, the navigator can make an observation on one of the several pulses, visually disregarding the others. Of course, a steady, well-shaped pulse must be employed, and general experience has shown that only the first sky wave to arrive, from the so-called E_1 layer, is satisfactory. Corrections must be made for the delay in transmission caused by the increased path length and the ionized region through which the wave travels, but these corrections have been computed once for all and appear intrinsically in the Loran charts. The situation is not quite so simple at the very long wavelengths, such as those used in Low Frequency Loran, where for technical reasons the pulse length cannot be made short enough to insure separation. Also, sky waves are present even in daytime, resulting in less variation in operation between daytime and nighttime. At these wavelengths ground wave operation should be adhered to for most consistent results ; it is not believed that the question as to whether consistent results may be obtained when the sky wave is very large compared to the ground wave has yet been resolved.

3.0. Accuracy

As with distance considerations, the accuracy obtainable under practical working conditions can only be obtained finally from statistical results of experience. Much experience has been had with some systems, less with others, hence it is worth while to represent the trends and general factors based on principles and experience.

The most fundamental aspect of the accuracy of pulse navigation systems goes back to the accuracy with which the velocity of propagation is known. In hypothetical vacuum, the velocity of radio waves is constant and equal to that of light. For a direct wave in the atmosphere, it may vary, depending upon the dielectric constant of the region, which in turn depends on temperature, pressure and humidity, and on any ionized condition of clouds, droplets or other particles. The ground wave velocity depends also on the characteristics of the water over which it propagates. Fortunately, the variations in velocity experienced in these cases are of negligible magnitude for all ordinary marine navigation and may be left out of consideration.* The sky wave travels partly through normal atmosphere and partly through a more or less intensely ionized region. Its velocity is quite different and variable while in the ionized region. Furthermore, the waves of the several frequencies represented by the spectrum of het train of pulses may have different velocities and different paths, with the result that some portions of a pulse may arrive at different times from others. These peculiar phenomena distort and delay the shape of the pulse received by the navigator and cause an inaccuracy in his reading. Although they do cause errors, careful operational techniques can hold them within tolerable values.

Another important aspect of accuracy is that of producing trains of pulses of satisfactory shape and of measuring the associated time intervals or differences. The length of the individual pulses in the train should preferably be quite short and with sharp frontal shape in order that the measurements made by the navigator of time intervals or of time differences can be accurate. There is a practical minimum to the number of individual oscillations of carrier frequency that may be worked with however, which is usually put at about 50 oscillations per pulse and as the carrier frequency is decreased the pulse duration must be made longer and longer. Lengthening the pulse duration eventually leads to degradation of accuracy. Of more concern is the problem of radiating at the longer waves pulses with very sharp fronts. The Fourier analysis of this problem, in which the pulse train is resolved into its many component frequencies or spectrum, indicates that the antenna and associated circuits must be capable of faithfully transmitting a relatively broad band of frequencies. With carrier frequencies above about one megacycle no unreasonable difficulty is encountered, but for frequencies of lower value, or at longer wavelengths, the design of satisfactory antennas with low Q is very difficult and their size and cost are large.

A third factor of prime effect on accuracy is

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* However, in applications requiring extreme accuracy, such as surveying, chart control, geological exploration, etc., corrections must be made.

that of the geometrical relations involved in the system. With straight radar and other radial systems, where a position is determined from a distance and a bearing taken from the ship, or from a shore point if land-based radar were employed, the accuracy of fix generally decreases with increasing distance and with increasing wavelength. The accuracy experienced with present marine radars is quite good over the distances for which it is intended, viz., of the order of 100 yds. at the close-up distances and increasing to 2 per cent. of distance at the greater values, and about 2 deg. in bearing. Both circular and hyperbolic navigation systems depend first of all on the length of the base line between the transmitting stations, which, if adequate individual station coverage is present, should be as great as possible. Circular systems which measure two distances from which the fix is obtained can be designed to give high accuracies, perhaps higher than those of any other system. As an example, the Shoran system has given probable errors of distance measurement of the order of magnitude of 50 ft. in airplanes out to the limit of its range. It should be pointed out, however, that the high accuracy is in part the result of the very short pulse lengths that can be used at very short wavelengths. The reason the circular system is not well adapted to ordinary marine navigation is mainly that an adequate antenna and transmitter aboard ship is not too practical; a saturation of service also limits its usefulness.

In addition to base line magnitude, the accuracy of a fix in both circular and hyperbolic systems varies with the angle made by the base line and a radial line drawn between base line centre and ship, and with the length of the radial line. Accuracy is greatest when the two lines are at right-angles, practically zero when they coincide. Hyperbolic systems employ three or four shore transmitters and the same considerations apply although with different details. Since one pair of stations provides only a line of position, the accuracy of a fix depends on the certainty with which two lines can be determined and the geometrical relation of the shore transmitters and the ship. Proper location of shore stations is thus important. In experience so far, it has frequently been possible for the navigator to select any of several lines of position from different shore stations in order to use pairs of lines that intersect with an angle not too far from a right-angle, or to select three or more lines simultaneously; this procedure may be compared to the proper choice of celestial bodies in taking star sights. The accuracy of both circular and hyperbolic systems becomes less with increasing distance, but usually the practical situation does not require accuracies as high at the extreme distances as at the shorter ones. Generally, a circular system possesses a geometrical accuracy which may be as much as roughly four times as great as that of the equivalent hyperbolic one. Experience with present marine Loran has indicated that errors of not more than about 2 miles at 500 miles can be expected.

Accuracy of a system also depends on the manner in which the received pulse trains are measured in order to obtain distance or difference in distances. The receivers used in pulse navigation systems customarily employ a cathode-ray oscilloscope. The trace on the fluorescent screen is controlled by the received train of pulses and by an accurately timed sweep circuit synchronized with the pulse train, providing a detailed picture of the received pulse train. The several systems differ in the manner in which the pulse interval is measured. In radar, although a plan-position indicator with an adjustable distance marker is usually employed, in principle the measurement is made by placing a distance indicating pulse in coincidence with the reflected pulse and reading the distance from the adjusting circuit calibrations. Errors occur because of the finite and somewhat distorted shape of the reflected pulse, and because of circuit inaccuracies. In another system, exemplified by Gee, the two pulses that are to be compared are placed opposite each other after one has been inverted. There is an inherent error in making this placement because of the apparent shape of the leading edge of the unequalized pulses. A more accurate system is employed in Loran in which the two received pulses are equalized in amplitude and then bodily superimposed on the screen, care being taken to fit the leading edges. The theoretical improvement in this respect of Loran over Gee has been estimated at about 10.

The time required to take readings with pulse navigation aids should not be greater than about 2 to 5 minutes, so it is only in the case of the fastest ships that any corrections for the change in ship's position between observations need be considered.

4.0. Comparison of Pulse and Continuous Wave Navigation Systems

Any comparison between pulse and continuous wave systems must either be extremely detailed and lengthy, or else brief and superficial. The latter course will be followed here. Fundamentally, it is possible to duplicate the pulse navigation systems with an equivalent continuous wave system, if in effect "Wave" is substituted for "Pulse" and "Phase" for "Time Difference," with corresponding associations in the transmitting and measuring systems. The measurement of phase is, however, periodic, giving rise to ambiguities of a high order in all high-skill accuracy navigation systems which utilize phase measurement of continuous waves. Various schemes have been proposed for the resolution of these ambiguities, usually requiring the addition of secondary systems of lower order of accuracy which, in combination with the basic system, reduce the number of ambiguous regions. Such systems usually necessitate an extremely complicated receiver or a complex operating procedure that requires considerable time to carry out. Phase measurement systems may also eliminate or reduce the ambiguous regions, with a corresponding reduction in accuracy, by using short base line lengths of only one-half to several wavelengths between the two shore-based stations of a pair. However, the order of magnitude of error of fix to be expected is about 25 miles or more at a distance of 500 miles for a half-wavelength base line and no ambiguous region. The greater this base line is made the higher becomes the accuracy, and the larger is the number of ambiguous regions. When compared with the pulse navigation systems, these expedients appear as very elaborate equivalents of the elegantly simple pulse method which directly and with finesse solves the problem of short- and long-distance navigation.

In a continuous wave system, there is no means for separating the ground and sky waves. At very high and microwave frequencies this presents no difficulty, since neither of these rays reaches the receivers in any case, but at medium and low frequencies used for medium and long-range navigation systems, the addition of the sky wave energy to that of the ground wave with more or less random phase has a disastrous effect upon the accuracy of measurement. At distances where the sky wave is about equal in intensity to the ground wave, the variations caused by the sky waves are such as to slide the indications of phase from one region of ambiguity to another, thereby completely destroying the indication. Thus the maximum distance of the continuous wave systems is about the same as the minimum distance at which sky wave operation of pulse systems becomes useful.

A continuous wave system, in general, requires one channel for each transmission. A long base line hyperbolic continuous wave system would require at least three clear channels to provide a fix, while one with a short base line will require at least two channels. By contrast, many pulse systems, with their visual resolution of pulse trains, may be operated simultaneously on the same frequency by the simple expedient of assigning specific pulse repetition rates to each transmitter or transmitter pair. The navigator is easily able to select the particular transmitter he wishes to observe without interference from the others, and it is estimated that between 10 and 20 such simultaneous channel-shared transmitters are practical. This important feature of pulse systems makes them relatively economical of spectrum utilization compared to continuous wave systems.

5.0. Equipment Reliability

There is no doubt that the electronic gear required for pulse navigation contains many intricate and complex parts, and that its introduction into the conservative maritime world will be met by opposition from some on this score. As an aid carried aboard ship it will require a certain reorientation of the officer personnel and the institution of a small amount of additional maintenance and operational effort. To those familiar with the successful employment of this and even more complicated equipment under the most adverse conditions of the war, there can also be no doubt about the success with which marine radar, Loran and other similar equipment can be assimilated by those who operate ships in peace. For those who are inclined to think the difficulties are great, it may be recalled for their encouragement that some persons experienced in airplane operation were afraid that the new radar gear introduced in a steady stream during the war might not be serviceable and were later surprised, and pleased, that it could generally be kept in operation just as easily as could the plane itself.

It appears certain that there are a number of commercial organizations convinced, and ready to back up their conviction, that peace-time radar marine navigational aids will be far more rugged and reliable than any equipment of war-time vintage and quite up to the standards expected in maritime service. No doubt the magnetic compass seemed very delicate and technical to those brave men who prior to its use sailed vast water areas in cockle-shells ; and many of us can recall the introduction of those far more complicated devices, the gyro-compass and the radio communication equipment, which are now accepted aboard as firmly as is the anchor.

No present or past navigational means has ever been able to provide position at every hour and with full accuracy. Celestial, lunar, and solar observations are notoriously most difficult to obtain in foul weather when needed most. The vicissitudes of dead reckoning and even radio direction finding are found in every log and in the records of marine insurance companies. Let us hope and trust that no bogy of alleged complexity will retard the availability of substantially continuous and complete navigational data from pulse systems in marine service.

6.0. Current Pulse Navigation Systems

6.1. *Short-distance Systems*

6.1.1. Radar

A recent development of extreme importance to marine navigation and pilotage has been the Radar. As now developed, the Radar sets available for marine use are so-called "Surface Search Radar Sets." They present, upon a cathode-ray indicator, a radar picture of the region about the vessel, including indications of other vessels, buoys, and some topographic features.

Usually an adjustable distance-indicating system is provided in the indicator, which produces a circular trace on the screen. This trace may be made to coincide with the spot caused by the object whose distance is desired, and the distance may then be read from a calibrated scale. Such a distance-measuring system converts the PPI radar into a circular navigation system if two known points are identified on the screen. Accuracy of position, determined in this manner, is correct to within 2 per cent. of the range ; a precision somewhat better than can be obtained from range and azimuth indications. The radars for marine use operate on wavelengths between 1 and 10 cm. The normal range from antenna heights usually available aboard ship is from 20 to 25 miles. In certain locations so-called anomalous propagation occurs with surprising frequency and then the distance may be 40 or 50 miles and even more. Unfortunately, this atmospheric condition seldom occurs during fog and bad weather, and may not occur at all in most localities.

The radar is a versatile short-distance device. It provides the most satisfactory means of warning against collision, and because of the completeness of information makes ship movements in the presence of other ships not only possible but safe as well. It provides bad-weather pilotage, and harbour and coastal navigation. It is self-contained in the sense that no co-operating shore stations are required. It provides the captain directly with the information from which he alone makes piloting or navigational decisions, and therefore leaves completely within his authority the movement of his ship. Its usefulness is greatly extended by the installation of suitable reflectors and radar beacons in congested waters where such aids are economically feasible.

6.1.2. Radar Beacons

A radar beacon is a radar receiver-transmitter combination that may be installed at some fixed location and arranged to reply to a radar interrogation with a coded response. This coding positively identifies the transmitter, and extends the maximum distance and accuracy of measurements upon the beacons. Distances in excess of 50 miles are readily achieved. Satisfactory beacon designs have been made, but there has been no extensive installation as yet. This is largely due to lack of standardization both of marine radar equipment and of beacons. The employment of beacons at a selected number of sites, including those now occupied by lights and light ships, would greatly enhance the value of shipborne radar.

6.2. *Medium-distance Systems*

6.2.1. Shoran

The Shoran system is a circular navigation system, operating in the frequency band from 220 Mc/s to 260 Mc/s. It consists of two beacon-type ground stations and a transmitter-receiver installation. The Shoran system is essentially an aircraft positioning system of extreme accuracy over distances of perhaps 250 miles to an aircraft flying at 40,000 ft. At this distance it will give positional information accurate to within 50 ft. If adapted to marine use the distance would be reduced to perhaps 50 miles with the same accuracy. For general marine use, Shoran could be valuable as an inshore piloting aid, where its extreme accuracy would be valuable, although saturation of service might be a problem. It can be used as a control for hydrographic, geodetic and geologic surveying, and could be employed for precisely holding the position of a lightship or floating beacon. Shoran equipment is completely developed and complete equipments are available. No permanent installations are believed to have been made and general service is nowhere available at present, nor is it proposed.

6.2.2. Gee

The Gee navigating system is a hyperbolic system operating on direct waves in the frequency bands between 25 to 85 Mc/s. It was developed as an aircraft navigation system and is said to provide coverage for any number of craft with an accuracy of from $\frac{1}{4}$ to $\frac{1}{3}$ mile up to distances of 250 to 300 miles, depending upon the altitude of the craft. Again, for marine use the range would be restricted to line of sight from masthead, i.e., to 40 to 50 miles. For general marine use, Gee might be useful as an inshore and coastwise piloting aid. The fact that Gee, as a hyperbolic system, cannot be saturated, is an advantage in a congested region. Gee is a British development, and at present quite complete coverage of the British Isles is in existence. The equipment has proved to be reliable, simple to operate and to maintain.

6.3. *Long-distance Systems*

6.3.1. Loran

Loran is a hyperbolic system operating in the frequency band of from 1·7 Mc/s to 2·0 M/cs. The transmission is either by ground wave and/or by single reflected sky wave. The primary service distance is about 700 miles from the most distant station by ground waves, with a maximum positional error of 5 miles at that distance. This distance and accuracy is available day and night, over water. At night, the first reflection from the ionosphere has proved strong and stable enough for navigation, giving a fix with an error between 5 and 10 miles at ranges out to 1,400 miles from the most distant transmitter. The Loran system has been subject to an intensive development programme during the last five years. The night service area of Loran presently covers one-quarter of the surface of the earth.

6.3.2. L.F. Loran

The L.F. Loran system is a hyperbolic system operating with a carrier frequency of 180 kc/s. It is derived from the standard Loran system and uses the same repetition rates and pulse patterns. The same receivers and indicators may be used by a small radio-frequency converter. An experimental chain has operated for about six months along the east coast of the United States. This chain has been taken out of service and at the time of writing another chain is operating in northern Canada. The low carrier frequency makes it inconvenient to make the pulses short enough to separate the ground and sky waves. However, it is usually feasible to recognize that portion of the pulse due to the start of the ground wave, so that consistent operation may be obtained by careful operation. There is no commercial service available at the present time. It is confidently expected that the continued experiments on this system will demonstrate favourable characteristics.

7.0. The Present Situation

The present situation is full with the opportunity for progress. We have available now adequately proved electronic systems of sufficient technical capacity to solve the navigational problems of ship movement under substantially any condition of weather on oceans, along coasts, in harbours, on lakes, and on rivers. The value of such improvements in ship movement lies in the added safety and in the reduced costs of water transportation obtained when freedom from being slowed up or hove to from weather, darkness, and traffic density is secured.

The tremendous effort represented in this technological advance made during war should be taken advantage of now because no similar effort will be possible in a foreseeable time and nothing short of it is likely to result in anything but relatively minor improvements. It will be far more profitable to establish a satisfactory system now and get the use and experience of it for years than to await the achievement of an ideal system that may elusively escape capture for many long years to come. Aviation has suffered this sad plight and is to-day but little further toward the operational use of all-weather aids than it was 10 years ago. It is sincerely hoped that decisions will be made at this time to adopt, install and use in everyday operations a satisfactory and complete set of electronic navigation aids. If this is not done, the blame cannot be laid on the doorstep of technology but must be placed elsewhere.

To provide a complete set of electronic navigational aids, two separate types of equipment appear necessary, one for ocean navigation possessing moderate accuracy, and a second for close-in navigation or piloting inland waters and for warning of impending collision. No single equipment can do both jobs now or later. Different combinations of available and future equipment have been proposed, but for the various reasons advanced in this paper and elsewhere, it seems clear to this author that the combination of standard Loran for ocean navigation and shipboard radar for close-in navigation and warning is the best choice.

Standard Loran can now provide coverage over a very significant portion of the ocean areas and by the addition of more shore stations can be extended and improved to give still greater service. The equipment has been thoroughly tested and is immediately available. The shipboard equipment is relatively simple and economical. Engineering-wise, there is every reason to believe that the major system design parameters were originally well chosen by its developers and can be little if any improved. However, if later developments actually do offer improvements, it is most likely that they can be incorporated into the system without causing obsolescence of the vast quantity of navigational equipments that would presumably be in service. For example, should a very high frequency version of Loran prove of value for more accurate inshore navigation, it would be rather easy to convert the receivers to operate on this system too. Similarly, should further development of Low Frequency Loran bring about its adoption, it is believed that the same receivers could be simply converted.

Ship-based radar is perhaps not quite so well explored as is Loran, but it is nevertheless in a high state of development. The main questions remaining involve the precise wave band in which it should operate and the degree of elaborateness with regard to piloting ease. Neither question, it is submitted, is of grave enough importance to justify a protracted delay in adoption. Until a standardization of some sort is effected, the establishment of beacon stations cannot be got under way, and beacons should be installed and maintained as rapidly as possible to enhance the usefulness of marine radar.

With regard to future possibilities, it will be sufficient here to say that of course scientists and engineers can and undoubtedly will bring about some worthwhile new developments or improvements of present equipment. New indicators, new systems, automatic reading navigation systems, automatic controlled steering, full automatic and accurate continuous position recording, automatic collision warning, and other easily conjured up ideas may tickle the technical palate now and may, some day, but not soon, be offered for commercial use.

GRADUATESHIP EXAMINATION, MAY 1950

PASS LIST

A total of 337 candidates entered for the whole or part of the May 1950 Graduateship Examination. This list contains the results of all successful candidates.

ELIGIBLE FOR TRANSFER OR ELECTION TO GRADUATESHIP OR HIGHER GRADE OF MEMBERSHIP

The following candidates have passed the entire examination, or having previously passed or been exempt from part of the examination, have now passed the remaining subject(s).

ABBOTT, Percy William (S)	Watford
BAIN, Wilfred Alec (S)	Enfield, Middx.
BROWN, Alan (S)	Watchet, Som.
CAMERON, Peter MacDougall (S)	London, N.22
CHAUDRI, Enver Hussain (S)	Ipswich
COOPER, William John (S)	Epping, Essex
DUNCAN, Malcolm John (S)	London, N.13
EAGLES, Dennis James (S)	London, W.3
FENWICK, William Alfred (S)	Chesterton, Cambs.
GEORGE, George Naguib	Heliopolis, Egypt
GIBBS, John Bernard (S)	Mansfield, Notts.
HARRINGTON, Philip (S)	Dublin
HOPKIN, Peter Roy (S)	Hadleigh, Essex
KRISHNAN, Triplicane Asuri (S)	Madras
KULKARNI, Anant Keshav (S)	Poona
KUNDAPURKAR, R. Umeshrao (S)	Bombay
LATIF, Moiz Ebrahim (S)	Ahmedabad, India
LAURENCE, Roger Frederick	Guildford
MISRA, Awadh Narain (S)	Allahabad, India
MORGAN, Stephen Lascelles (S)	Johannesburg
PARKES, Gregory Wilson (S)	London, S.W.14
PROWSE, Michael John (S)	Staines, Middx.
RAGHANATH RAO, Arani Laxmi (S)	Bezwada, India
RAMASWAMI, Subramaniam (S)	Saharanpur, India
REANEY, Donald (S)	Liverpool
REID, Andrew Michael (S)	Newcastle-on-Tyne
REYNOLDS, Peter Harold	Halstead, Kent
ROBINSON, John (S)	Hull
ROWLANDS, John	Deganwy, Caerns
SCHOLEY, Douglas Herbert	Nairobi, Kenya
SEK, Stanislaw (S)	Castleton, Lancs.
SELINGER, Cyril (S)	London, N.W.6
SMAILES, George (S)	London, W.1
SNOWSILL, Alan Harold (S)	London, S.E.21
SRINIVAS, V. A. (S)	Madras
THORN, Roger (S)	Newbury, Berks.
TWIGG, George Sydney (S)	Sheffield
WILD, Sydney	Ashton-under-Lyne, Lancs.
WILKINSON, Stanley Henry (S)	Three Bridges, Sussex
WINTER, Simon Chapman (S)	London, N.W.4

The Following Candidates Passed Part I Only

BROOKS, William Gilbert (S)	Tangmere, Sussex
CARTER, John Kesterson (S)	London, N.13
CHANG CHOON YE (S)	Medan, Sumatra
COOPER, John Cedric (S)	Isleworth, Middx.
COSTELLO, Daniel James (S)	Dublin
ELVIDGE, Roy Wallace (S)	London, S.E.13
ENTWISTLE, Roy (S)	Palmerston North, N.Z.
GOEL, Sumraj Mall (S)	Delhi
LODDER, Albert Stanley (S)	Carshalton, Surrey
MARSDEN, Ernest Wilson (S)	Westcliff-on-Sea
PANCHOLI, Chandrashanker (S)	London, W.4
PORTER, William Edmund (S)	Butwell, Notts.
REDFERN, Ralph Frederick (S)	Rotorua, N.Z.
REIDY, Kevin John (S)	London, N.16
TIMMINS, Walter Bryson (S)	Toronto
TOMPKINS, Stanley James (S)	Newcastle-on-Tyne

(S) denotes a Registered Student.

The Following Candidates Passed Part II Only

ANDREWS, William Gordon (S)	Liverpool
BEBBINGTON, Roy Edward (S)	Yeovil, Som.
BENNETT, Wilfred Dennis (S)	Manchester
BHATTI, Dharam Singh (S)	Nagpur, India
BHATTI, Mukhtar Hamid (S)	Lahore, Pakistan
BURRILL, Kenneth Arthur (S)	Harrow, Middx.
CAMERON, Archibald (S)	Glasgow
DODDS, John Arthur (S)	Harrow, Middx.
EVANS, Hugh Maitland (S)	Newbridge, Mon.
FISCHL, George (S)	Richmond, Surrey
GRAY, Robert Frank (S)	Weybridge, Surrey
HEAD, Reginald Edward (S)	Wolverhampton
KANOJIA, Babubhai (S)	Dakor, India
KATRAK, Behram (S)	Bombay
KHANNA, Suraj Parkash (S)	Delhi
MacDONALD, Calum Archibald (S)	Isle of Mull, Scotland
McILWRAITH, John W. (S)	Portsmouth
MAHENDRU, Prem Das (S)	Amritsar, India
MURZELLO, Neri (S)	Bombay
PAYNE, Stanley Frederick (S)	Cross Keys, Mon.
RAJKUMAR, Gnanapragasam Manuel (S)	Anaicoddai, Ceylon
RAMTOOLA, Mohamed Jackaria (S)	Colwyn Bay
RANGA RAO, Katipamula Venkata (S)	Khargpur, India
ROBINSON, Gordon S. (S)	Whitby, Yorks.
RODMELL, Edward Cripps (S)	Chipping Norton, Oxon.
ROY, Ranjit Kumar (S)	Delhi
SHAMBAVI DEVI, P.S. (Mrs.) (S)	Madras
STEWART, Edward Samuel (S)	Christchurch, N.Z.
TILLEKERATNE, Liyanarachchije (S)	Colombo
TOLIA, Tarachand J. (S)	Saurastra, India
TURSKI, Stefan (S)	Dundee, S. Africa
UPCOTT, Gilbert Spencer (S)	London, N.17
VISWANATHAN NAIR, N. (S)	Bombay
WADHWA, Balwant Singh (S)	New Delhi
WILLIAMSON, Robert (S)	Didcot, Berks.
WOODS, John Joseph (S)	Milltown, Co. Kerry

The Following Candidates Passed Part III Only

ANDERSON, Charles W. (S)	London, W.2
BOWN, Peter Edward (S)	London, S.W.14
FLANNERY, Thomas J. (S)	Southampton
TABART, Francis Ernest (S)	London, S.E.3

The Following Candidates Passed Part IV Only

AGARWAL, Chunni Babu (S)	Mhow, C. India
ANIKHINDI, Ramesh G. (S)	Poona
ATHERTON, Neil	Swindon, Wilts.
BALASUBRAMANYAM, T. (S)	Delhi
CHAPMAN, Derrick J. (S)	Ludlow, Salop
CHRISTIAN, Robert G. (S)	Billericay, Essex
CUNDY-BORGE, Roy (S)	Plymouth
DESHPANDE, Purushottam Damodar (S)	Nagpur, India
DUNN, John William (S)	Prestwick
FAUTLEY, Raymond F. (S)	Ewell, Surrey
KULKARNI, Anant Ambadas	Bombay
LEAN, James Leslie (S)	Townsville, Au .
NYAYADHISH, Vishnu B. (S)	Bombay
ROBERTS, Kenneth Nevil (S)	Wigan, Lancs.
ROBINSON, Geoffrey Spencer (S)	Farnborough, Hants.
RONAN, Noel (S)	London, N.1
STEVENSON, Roy Neville (S)	Hertford
TAWADEY, Ashok Bapuji (S)	Mhow, C. India
TIDMARSH, Francis Henry (S)	Barkingside, Essex
TITHERADGE, John P. (S)	London, S.W.16

The Following Candidates Passed Parts I and II Only

COOK, John Sutton	Sandwich, Kent
DICKSON, Paul Richard (S)	London, W.2
GUILDYS, Jonas Algirdas (S)	Toronto
McDONALD, George Watt	Elgin, Morayshire
VISWANATHAN, S. (S)	Madras
WAISTELL, Fred (S)	Esh Winning, Co. Durham

The Following Candidates Passed Parts II and IV Only

GROVE, Cyril John (S)	Feltham, Middx.
MACKENZIE, Alasdair (S)	Greenock
SUBRAMANIAM, Coimbatore Panchanda (S)	Bombay

TRANSFERS AND ELECTIONS TO MEMBERSHIP

At the meetings of the Membership Committee held on July 11th and September 12th, 1950, there were thirty-four proposals for direct election to Graduateship or higher grade of membership, and forty-six proposals for transfer to Graduate or higher grade of membership were considered.

The following list of elections was approved by the General Council : Twenty-nine for direct election to Graduate of higher grade of membership and thirty-three for transfer to Graduate of higher grade of membership.

Direct Election to Full Member

Marriott, George Armstrong, B.A.(Cantab.)	London, W.1

Direct Election to Associate Member

Andrews, Robert Kenneth,	Calne, Wilts.
Arthur, Herbert	Enfield, Middlesex
Curtis, Samuel Claude, Sqd./Ldr.	London, N.W.3
Edwards, David George, Lt./Cmdr.	Ewell, Surrey
Gray, David Ewan	Nicosia, Cyprus
Hosburn, John Cadogan, Sqd./Ldr.	London, N.22
Overton, Philip Frederick, Wing/Cmdr.	Surbiton, Surrey
Satterthwaite, William Ernest, Flt./Lt.	London, W.5
Tulloch, Russell George	Christchurch, New Zealand

Direct Election to Associate

Bennett, Nicholas Wheatley	Pretoria, S. Africa
Bury, John Edward, Flt./Lt.	M.E.A.F.
Catty, Dennis Ivan, Flt./Lt.	Aberdeen
Fischmann, Arieh Franz	Haifa, Israel
Grace, James Joseph, Flt./Lt.	M.E.A.F.
Hall, Ephraim	Southampton
Martin, John Alexander	Cairo, Egypt
Poole, Walter Francis	Bexley Heath, Kent
Roberts, John	London, S.E.6
Rutter, Francis John	Hillingdon, Middlesex
Sharma, Dhani Ram	New Delhi, India
Smith, Thomas Deniston	Preston, Lancs.
Walker, Robert Alex.	Ruddington, Notts.

Direct Election to Graduate

Akruk, Waleed A. R.	Southampton
McGregor, Peter	Aberfeld, Perthshire
Mitchell, Charles Alfred	Portsmouth
Morleigh, Sidney	London, N.16
Northall, Bertram Victor	Newton, Co. Durham
Reynolds, Peter Harold	Halstead, Surrey

Transfer from Associate to Associate Member

Aitken, William A. S.	London, W.4
Beere, Graeme Maunsell, Lt.(L), B.Sc.	Auckland, New Zealand
Haigh, Kenneth Richardson	New Malden, Surrey
Jablonski, Jan	Hayes, Middlesex
Krishan Datt, Sharma	Jannagar, India
Laurence, Roger Frederic	Guildford, Surrey
Rowe, Harry Shaw	Limassol, Cyprus
Smith, Harold, Capt.	Manly, Australia
Sproson, James, M.B.E.	Manchester, 14
Susskind, Charles, M.Eng., B.Sc.	New Haven, Conn., U.S.A.

Transfer from Graduate to Associate Member

Cameron, Hector Francis Lovett, B.A.(Cantab.)	Weybridge, Surrey

Transfer from Student to Associate Member

Odell, Harold Arthur	Cheam, Surrey
Twivey, Derrick, B.Sc.(Eng.)	London, W.5

STUDENTSHIP REGISTRATIONS

In addition to the list of Studentship Registrations published in the June issue of the Journal, the following forty-one Studentship proposals were dealt with at the meeting of the Membership Committee held on September 12th, 1950. The following registrations have been approved by the General Council.

Aggarwal, Dharamdev, B.Sc.	East Punjab, India
Anning, Keith William	Sydney, Australia
Ansari, Sabir Husain, B.Sc.	Moradabad, India
Baker, Dennis	London, S.W.1
Baldwin, Leslie	Plymouth, Devon
Barry, Albert William	Chard, Somerset
Bridger, Stanley	Swindon, Wilts.
Brook, Brian	Huddersfield, Yorks.
Betteridge, John Edward	Ewell, Surrey
Buckwell, Richard Paul	Hove, Sussex
Clarke, George Frederick	St. Leonards-on-Sea, Sussex
Collins, Leslie George Herbert	London, S.W.16
Dawson, Terence Douglas	Beckenham, Kent
Diver, Norman William	Westcliff-on-Sea, Essex
Dyer, Peter Crighton	Bingley, Yorks.
Eastty, Charles Edward	Mitcham, Surrey
Farooq, Mohammad Omar	Southampton, Hants.
Hickling, Alfred	Gt. Malvern, Worcs.
Johari, Maharaj Bhhadur, B.Sc.	Nagpur, India.
Kakra, Chhetra Pal Singh, B.Sc.	Aligarh, India.
Kapur, Harkishan Lal	New Delhi, India
McKenna, Joseph	Thursday Is., Australia
Maltby, Dennis Hugh	Birmingham
Martinez, Perez Antonio	London, W.2
Martinez, Perez Pedro	London, W.2
Nicolaidis, Nicolaos	Niccaia, Greece
Rehani, Prabh Dyal	New Delhi, India
Reid, John Michael	London, N.21
Rosen, Salomon	London, W.1
Sahai, Prem Mohan	Bareilly, India
Sanders, Kenneth William	West Croydon, Surrey
Sanvoisin, Derek Clive	Edgware, Middlesex
Singh, Harcharn	Amritsar, India
Soe Myint	Weston-super-Mare, Somerset
Sundaram, Srinivasachari, B.Sc.	Madras, India
Swamy, Narayana Kavasseri G.	Poona, India
Srivastva, Mangla Prasad, B.Sc.	Gorakhpur, India
Suri, Vishwa Mitter, B.Sc.	Delhi, India
Venkatiswaran, Nellapalli Ganapathi, B.Sc.	Madras, India
Voon Kin Min, Andrew	Kuala Lumpur, Malaya
White, Cowin James	Gibraltar

TRANSFERS AND ELECTIONS TO MEMBERSHIP *(continued)*

Transfer from Student to Associate

Buckman, Robert Augustus Saka	Accra, Gold Coast
Burnett, Reginald George, Sqd./Ldr., M.B.E.	Singapore
Ellson-Jones, Frank	Bromborough, Cheshire
Ford, David	Christchurch, Hants.
Greene, Robert Emile	Newcastle
Ridgway, Harry	Wigan, Lancs.
Shepherd, Arthur William	Wellington, New Zealand

Transfer from Student to Graduate

Bain, Wilfred Alec Peter	Enfield, Middx.
Brown, Alan	Nr. Watchet, Somerset
Cameron, Peter McDougal	London, N.22
Eagles, Dennis James	London, S.W.19
Fenwick, William Alfred	Cambridge
Maunsell, Thomas	M.E.A.F.
Phillips, Alan David	Warrington, Lancs.
Robinson, John	Hull
Rottenburg, Ruben Robert	Haifa, Israel
Schild, Rolf	London, N.W.2
Sek, Stanislaw	Castleton, Lancs.
Smailes, George	London, W.1
Thorn, Roger	Newbury, Berks.

NOTICES

Radio and Television Servicing Certificate Examinations

The results issued by the Radio Trades Examination Board and the City and Guilds of London Institute show that 264 candidates entered for the Radio Servicing Certificate Examination held last May. Of these, 137 were successful (including 15 who were referred in 1949) and 45 were referred in the Practical examination.

The first Television Servicing Certificate Examination, held last May, was restricted to the London area and 30 entries were accepted. Of these, 16 candidates were successful and 12 were referred in the Practical. The remaining two candidates were unsuccessful. Pass lists will be published in the November Journal.

Technical Education and Skilled Manpower

The Parliamentary and Scientific Committee has recently published a report on "Technical Education and Skilled Manpower." The Committee, which comprises some 200 peers and members of Parliament and the representatives of 10 scientific and technical institutions, has previously published two other reports, "Universities and the Increase of Scientific Manpower" and "Colleges of Technology and Technological Manpower."

The present report deals only with the education and training of the skilled worker and this covers a field of enquiry beyond that previously considered.

Copies of the report may be obtained, price 1s. 3d., from the Secretary, 31 Palace Street, Westminster, London, S.W.1.

Telecommunication Equipment for Greece

As part of the complete reconstruction of the Greek telecommunication system, the Greek P.T. & T. authorities have ordered equipment for their main overseas radio-telephone link system from Standard Telephones and Cables, Ltd. This will provide telephone circuits with the U.K. and the U.S.A.

The equipment to be supplied covers the complete system and includes two 4-kW single-sideband transmitters for simultaneous working to London and New York, with a 40-kW power amplifier for use when transmission conditions are poor, two single-sideband receivers and equipment for connecting four speech circuits to the telephone network as well as a privacy system. Aerials, power plant, etc. are also being supplied.

Principal—Norwood Technical Institute

W. J. Thomas, Ph.D., B.Sc.(Hons.), (Associate Member), has been appointed Principal of Norwood Technical Institute. He was previously Vice-Principal. Dr. Thomas has served on the Education and Examination Committee of the Institution since 1948 and he has been a member of Council for the past two years. Details of Dr. Thomas' career were given in the January issue of the Journal.

The Scientific Film Association

Reference has frequently been made to the Scientific Film Association in these columns and we have been asked to draw the attention of members to the Association which is anxious to increase its membership.

The Association was formed in 1943 with the object of promoting a wider understanding of science and the scientific outlook by means of films. To this end the Association maintains an information service on scientific films, and grades them according to merit and suitability for various audiences. A list of 250 films on electrical subjects is to be issued shortly.

Members who are interested are invited to write to the Hon. Secretary, Scientific Film Association, 4 Great Russell Street, London, W.C.1.

Canadian Television Expansion

Hitherto Canada's television programmes have come from U.S. stations situated near the border. Soon, however, transmitters are to be set up at Toronto and Montreal, and a large expansion of the Canadian radio industry is expected.

We are advised by the Ontario Immigration Department that there are excellent opportunities for British engineers, and a number of experienced television service engineers are required immediately in Ontario.

Further information may be obtained from the Ontario Immigration Department at Ontario House, 13 Charles Street, London, S.W.1.

London Section Meetings

The attention of members is drawn to the fact that London Section Meetings will not be held on the same day of the month throughout the session.