REPORT 259-7*

VHF IONOSPHERIC PROPAGATION

(Question 41/6)

(1951-1953-1956-1959-1963-1966-1970-1974-1978-1982-1986-1990)

1. Introduction

The ionosphere, while primarily responsible for reflection of radio waves below 30 MHz, is capable of producing reflections in the VHF band (30 - 300 MHz) under some conditions, during relatively short periods of time and in certain areas of the world.

This report describes the conditions under which the E- and F-Regions produce such reflections, subdivided into normal and abnormal, in the sense that normal propagation can be forecast as a function of long range geophysical or solar parameters with a high degree of predictability on a daily basis, while abnormal means that its predictability is low on a daily basis, and only long term statistics provide some assessments of its behaviour.

It should be noted that ranges in excess of 1000 km may also result from the effects of anomalous tropospheric propagation through the non-ionized medium. Should it be necessary, or desirable, to identify the mode of an interfering signal, reference should be made to § 4, where the principal characteristics are tabulated.

2. F-Region

In this section, the F-Region is considered in relation to normal and abnormal propagation.

2.1 Normal F-Region propagation

Near the peak of the solar cycle long-distance transmissions via the F2 layer in mid- latitudes can occur for a significant fraction of the time up to 50 MHz or more. In low latitudes regular transmission will occur around 30 to 40 MHz, and such transmission can occur at 60 MHz and above. The lowest frequency at which interference due to such propagation becomes so infrequent as to be negligible is about 60 MHz for stations in mid- latitudes, and 70 MHz for stations at low latitudes (see Figs. 1, 2, 3).

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* This Report is brought to the attention of Study Groups 5, 8 and 10.

A report of normal propagation of television signals at very high frequencies has been produced in India [Saksena, 1979]. Also, propagation of VHF TV signals at about 60 MHz over a 3100 km path from Bangkok has been observed in India at Rohtak, particularly during equinoctial months and during a period of high solar activity due to propagation via the ionospheric F-layer at frequencies greater than the basic MUF. This signal reception was centred at 2000 local time with durations between one and two and a half hours [CCIR, 1982-86].

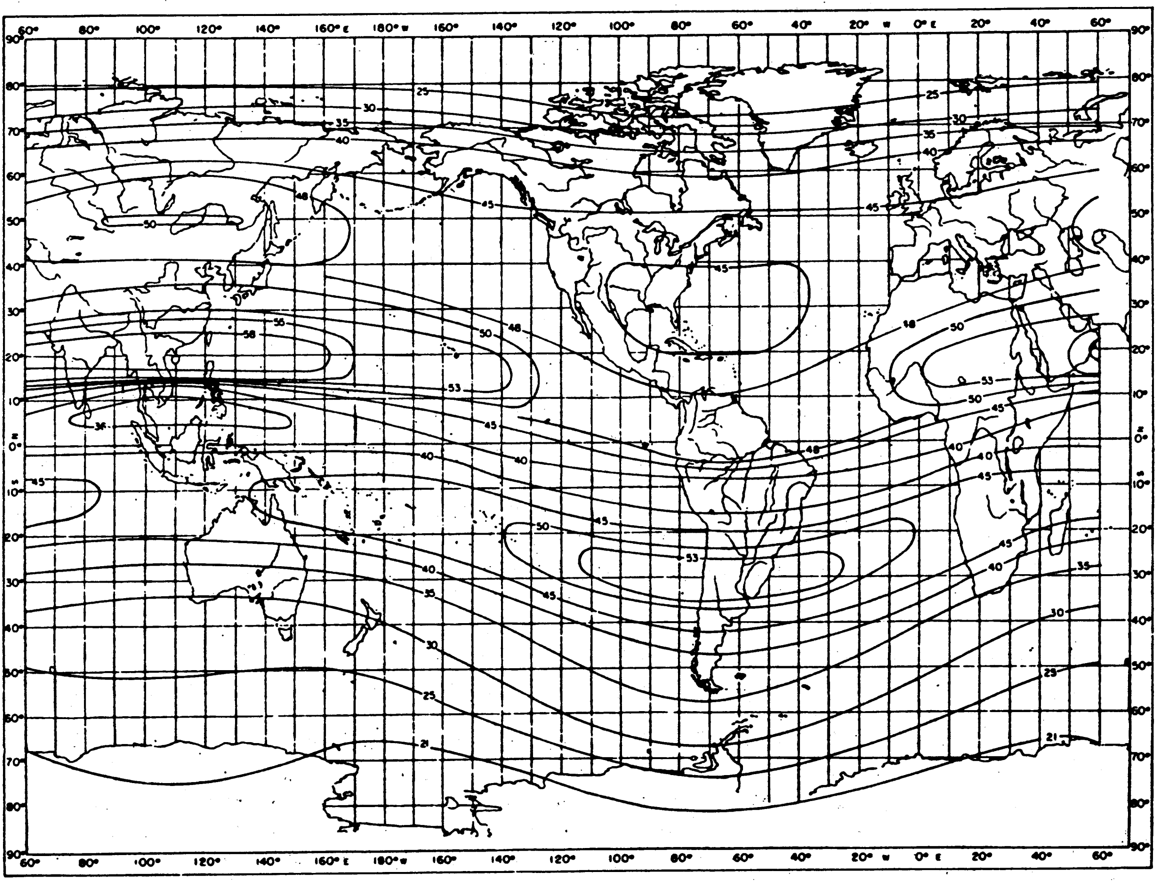


FIGURE 1 – *F2 (4000) MUF exceeded during 1 % hours – December solstice; sunspot maximum*

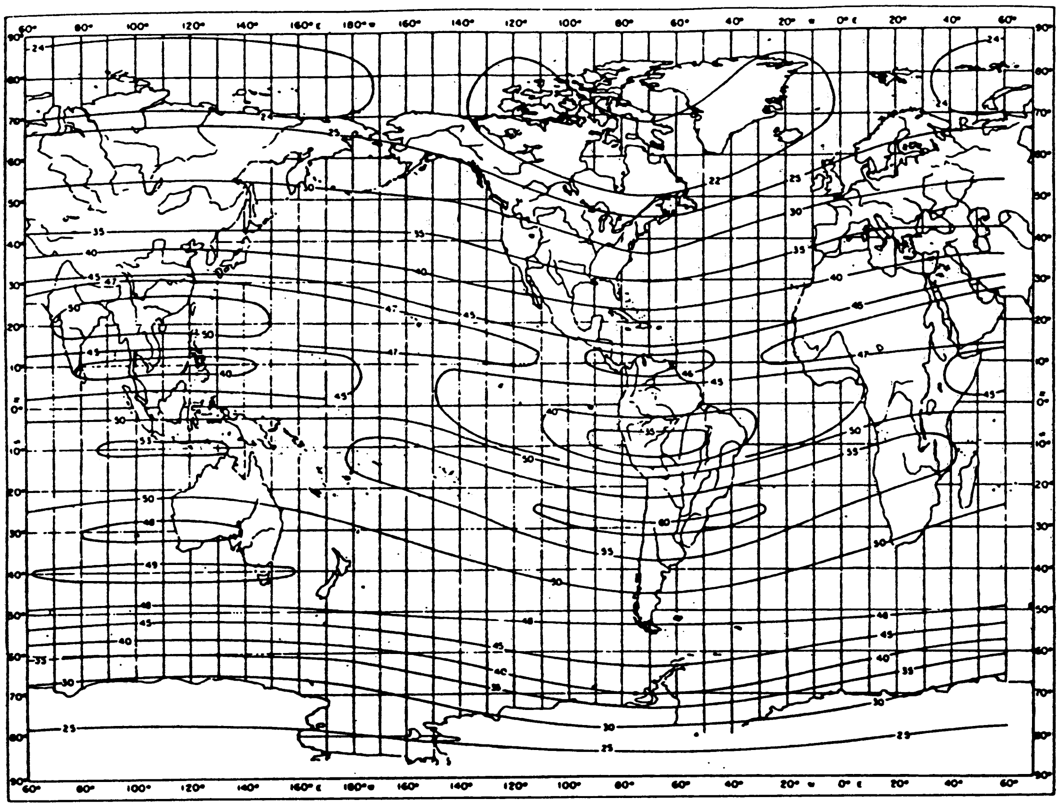


FIGURE 2 – *F2 (4000) MUF exceeded during 1 % of hours – June solstice; sunspot maximum*

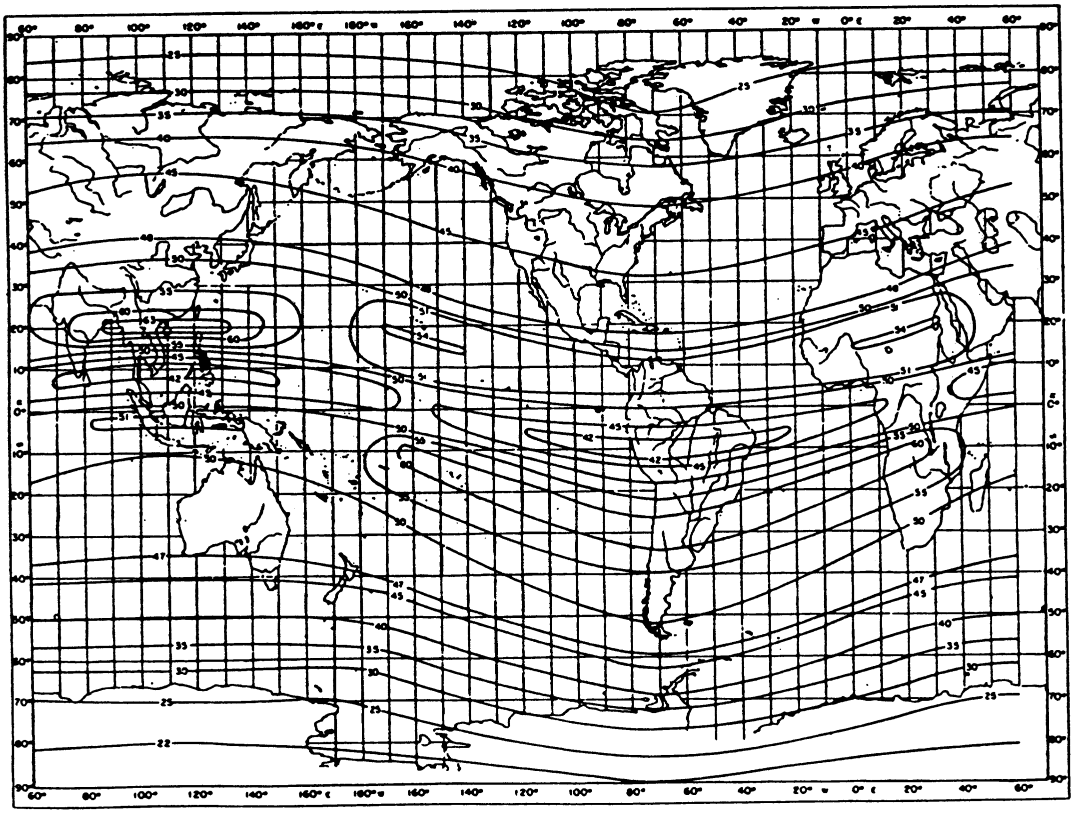


FIGURE 3 – *F2 (4000) MUF exceeded during 1 % of hours – Equinox; sunspot maximum*

2.2 Abnormal F-Region propagation

2.2.1 *Trans-equatorial propagation (TEP)*

Recent studies indicate that strong transmission can occur, particularly during high sunspot years, over long North-South paths spanning the magnetic equator. Most observations have been made by radio amateurs at a frequency of 50 MHz for paths of the order of 4000 to 9000 km; paths between South America-North America, Africa-Europe and Japan-Australia have been noted.

According to the experiment carried out between Australia and Japan during about one cycle of solar activity (1965-1974) at frequencies 32, 48 and 72 MHz, and during about a half-cycle of the activity (1969-1974) at additional frequencies 88 and 102 MHz, it was found that trans-equatorial propagation occurred at 32 MHz during a large part of the day (except a few hours in the morning) even in years of low solar activity. The hours of reception were increased with solar activity. At frequencies of 48, 72, 88 and 102 MHz, trans-equatorial propagation occurred after around 2000 h local time during both equinoctial periods and lasted for 6-8 h at 48 MHz, and 2-4 h at 102 MHz. Long-term variations of basic transmission losses at VHF which propagated over the trans-equatorial path are shown in Fig. 4 [Tao *et al.*, 1970; Kuriki *et al.*, 1972; Tanohata *et al.*, 1980]. On the basis of the signal levels observed on these four frequencies, the received signal power, normalized to 1 kW e.r.p. and using transmitting and receiving dipole antennas, is inversely proportional to a value between the 10th and 12th power of the frequency [Kuriki *et al.*, 1972].

It seems that propagation in the daytime is by the 2F mode, based on the equatorial anomaly; the night-time signal which exhibits rapid shallow fading is due to a scattering process associated with the equatorial spread-F [Tao *et al.*, 1970].

There appear to be two types of trans-equatorial propagation characterized by the times of peak occurrence, fading characteristics and modes of propagation. General reviews of TEP have been written by McCue and Fyfe [1965] and by Nielson and Crochet [1974].

The first type of TEP, which is called the afternoon type, has the characteristics:

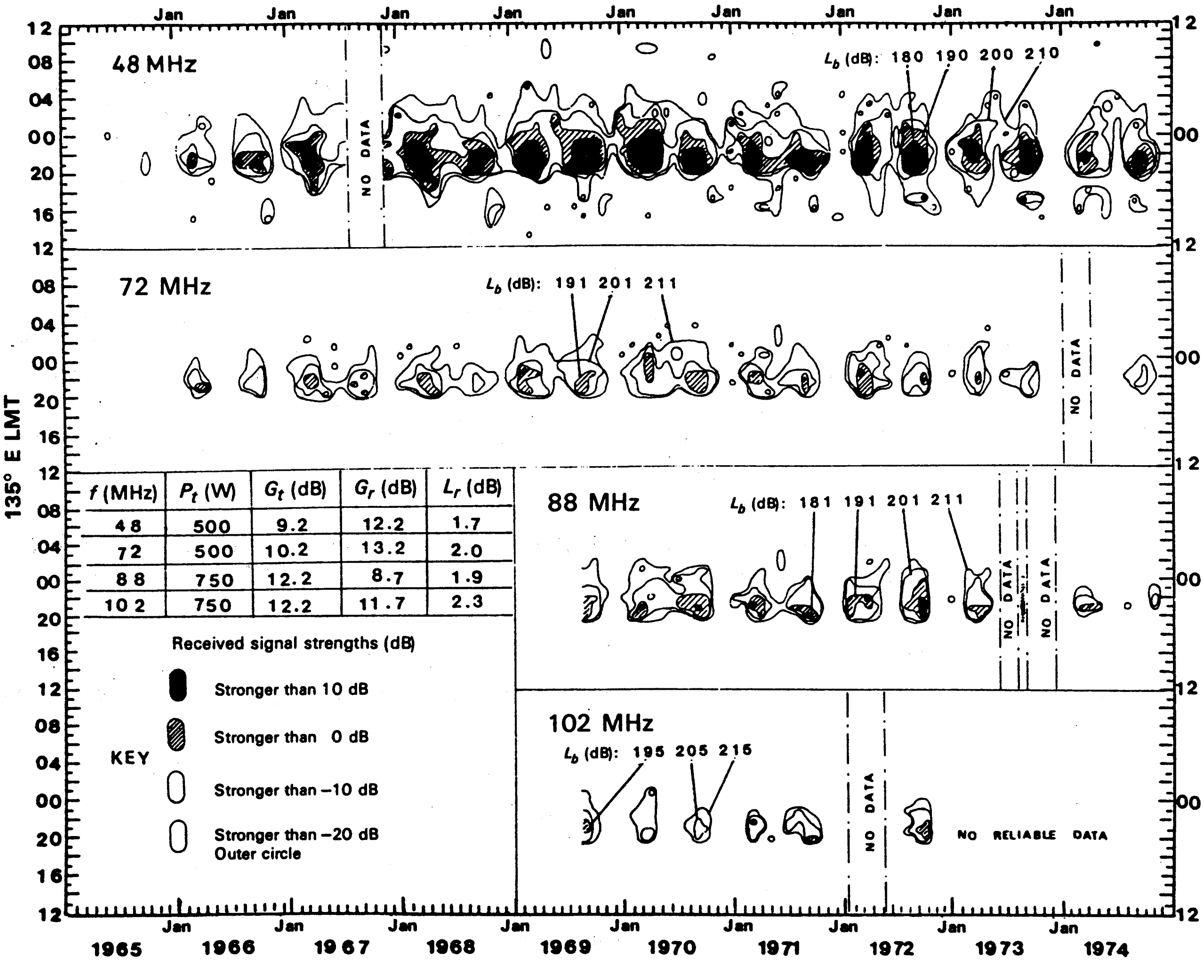
- a peak occurrence around 1700-1900 h LMT, the time being measured at the point where the circuit cuts the magnetic equator;
- normally strong steady signals with a low fading rate and a small Doppler spread (about ± 2-4 Hz);
- path lengths of about 6000-9000 km and sometimes longer.

It has been suggested by Gibson-Wilde [1969] that, in the Australasian zone at least, these signals probably travel by the "super-mode" or FF mode proposed by Villard *et al.* [1957]. Propagation by this mode involves two F-region reflections without an intervening ground reflection.

The second type of TEP, which is called the evening type, generally supports higher frequencies than the afternoon type and has very different characteristics:

- a peak occurrence around 2000-2300 h LMT;
- high signal strenghts but with deep and rapid fading at rates up to about 15 Hz and a large Doppler spread which sometimes exceeds 40 Hz;
- path lengths usually shorter than for the afternoon-type mode, being about 3000-6000 km.

The propagation mode for evening-type TEP is still uncertain. Different mechanisms have been proposed to explain this type of TEP; detailed explanations can be found in Bowen *et al.* [1968], Tao *et al.* [1970], Kuriki *et al.* [1972], McNamara [1973], Heron and McNamara [1979], Winkler [1981] and Ferguson and Booker [1983].



f (MHz)	P_t (W)	G_t (dB)	G_r (dB)	L_r (dB)
48	500	9.2	12.2	1.7
72	500	10.2	13.2	2.0
88	750	12.2	8.7	1.9
102	750	12.2	11.7	2.3

FIGURE 4 – *Basic transmission losses (L_b) and received signal strengths (V_r) indicated by open circuit antenna voltage*

P_t: transmitter power
G_t: transmitter antenna gain
G_r: receiver antenna gain
L_r: loss of receiving feeders.

Received signal strength is in dB(1 μV).

2.2.2 Other mechanisms of abnormal propagation

The studies indicate that there may, at times, occur bodies of ionization at heights different from those of any of the recognized ionospheric layers. Such ionization irregularities may occasionally give rise to reflections of waves in the 30 to 300 MHz range, the principal case being that of reflection from the edges or sides of magnetic-field aligned irregularities which occur within or near the auroral zone. Such reflections may constitute a source of interference to stations working in the 30 to 300 MHz range [Czechowsky, 1970].

Reflections have been observed via the F region, at frequencies appreciably above the F2 basic MUF but at intensity levels well below free-space. These reflections have been observed in the Far East, in South America and in Africa and appear to be a phenomenon of high sunspot years [Bateman *et al.*, 1959]. The equinoctial months appear to be favoured.

Enhanced MOFs are observed at night on Guam to N.W. Cape and Manila to N.W. Cape circuits during equinoctial months at high solar activity. The MOFs exceed the 2F MOF and often exceed 32 MHz, the upper limit of the equipment. They have been explained in terms of a two-hop propagation mode by McNamara [1974b]. Propagation on the first hop is deduced to be by scattering from field-aligned irregularities. The length of the first hop is assumed to be less than half the total circuit length, with the second hop being via the F layer and having a greater MUF than the second hop of a normal 2F mode.

2.2.3 *Ground and ionospheric side-scatter*

VHF radio waves propagated via the ionosphere have been observed to arrive at azimuths which differ considerably from the great circle direction. The signals are predominantly the result of multihop modes of propagation in which side-scatter occurs from irregularities at the surface of the Earth (Report 726). The intensity levels of the signals are well below free-space values and exhibit fading frequencies which are less than 1 Hz.

3. E-Region

VHF propagation by way of the regular E layer is unlikely at any time, whereas propagation by way of meteoric ionization or sporadic-E clouds can be significant.

3.1 Meteoric ionization propagation

Studies have been made in Canada, the Federal Republic of Germany, the United Kingdom, the United States of America and elsewhere, of the reflections which occur from meteor trails. Report 251 gives a bibliography on this subject.

Although of irregular occurrence, daily predictions of the durations of openings in the low VHF band can be made and, because of the daily occurrence, the openings are used for data transmission on dedicated networks.

3.2 **Sporadic-E ionization**

Sporadic-E ionization ———————— appears as an intensification in ionization in the form of a horizontal sheet of about 1 km average thickness and a horizontal dimension of the order of 100 km. The height is commonly 100 to 120 km. The sheets appear in a random manner but show distinct preference for certain times of day and months of the year (see also Reports 725 and 255). There are three major sporadic-E zones, in low, middle and auroral latitudes.

The low latitude zone is subdivided into two sub-zones, the equatorial zone and the sub-equatorial zone (see Recommendation 534). ——— The equatorial zone is a belt centred on the magnetic equator, extending about 6° in magnetic dip on either side of it. The edge of the belt shifts by approximately 1° of dip latitude between summer and winter, being at its greatest distance from the magnetic equator in the summer solstice. A highly transparent form of sporadic E (*q*-type) is a regular occurrence on the day-side of the belt and can be shown to be associated with the equatorial electrojet. Vertical incidence echoes produced by the equatorial Es layer, at frequencies above 7 MHz may be observed for a large percentage of the time, with substantial differences between the various continents [Giraldez, 1980]. Though there is no significant seasonal variation in the occurrence pattern, there is a tendency for the occurrence of equinoctial peaks for stations close to the dip equator, and solstitial peaks for stations a few degrees from it [Oyinloye, 1988]. Propagation of VHF signals via *q*-type Es is by scattering. The sub-equatorial zone extends on both sides of this belt up to ±20° dip latitude.

The mid-latitude zones cover most of the Earth and extend from the low latitude zone to a geomagnetic latitude of about 60° (actually to the line at which the occurrence of aurora is 15% of its maximum). The most dominant feature in the mid-latitude zone is the summer maximum in occurrence of intense sporadic E, which becomes more distinct as one moves to higher latitudes until it is sharply altered by auroral zone influences. Sporadic E rarely occurs between the hours of midnight and 0600h local time. It normally peaks around 1000h local time and in some areas exhibits a second peak in the afternoon or the evening. The sporadic-E layer is often very dense in the daytime. There are considerable longitude as well as latitude variations in the occurrence of sporadic E in the mid-latitude zones. The world-wide maximum is confirmed as being located between 120 and 160° east longitude and between 15 and 40° north latitude, geographic coordinates [Li Zanju, 1988]. A mechanism associated with wind shear appears most promising as an explanation for intense sporadic E at mid-latitudes.

In the auroral zones, the dominant feature is the night-time peak in the occurrence of sporadic E. The summer peak observed at mid–latitudes disappears entirely at the zone of maximum visible aurora. The auroral zones, like the equatorial zone, are regions of heavy current flow in the lower ionosphere. In addition, they are regions where ionized layers can be formed through the precipitation of charged particles. It appears that both of these phenomena may be responsible for the production of sporadic E. The occurrence of sporadic E in the high latitude zones is closely tied to the instantaneous auroral oval [Wagner *et al.*, 1973]. The role of charged particle precipitation, ionospheric currents and the wind shear mechanism in creating sporadic-E ionization and the morphology and structure of this ionization have been described by Hunsucker [1975], Wilson *et al.* [1976] and Wright and Hunsucker [1983]. The dominant production mechanism appears to be auroral particle (1-10 keV electron) precipitation. Hagg et al., [1959] found an interesting local time vs. latitude variation in the maximum occurrence frequency of sporadic E. (Note that present-day knowledge shows their explanation of the phenomenon to be incorrect.) At about 20 hours local time this maximum occurs at about 72° geomagnetic latitude; as local time increases the maximum swings gradually equatorward, reaching about 60° geomagnetic latitude at 03 hours local time.

3.3 Sporadic-E propagation

The occurrence of sporadic-E propagation decreases with increasing frequency. It might be considered a negligible factor above 100 MHz except as a source of interference to circuits with high reliability requirements.

3.3.1 Low latitudes

The reception of television signals in the band between 47 and 68 MHz in India has also been analysed [Saksena, 1979]. In addition, radio amateurs show great interest in Es activity and communications via Es up to frequencies of 144 MHz are often reported [CCIR, 1978-82].

Combination propagation modes, in which one hop is via the equatorial sporadic-E layer while the other is a normal, but long-distance, F-layer hop, have been deduced to exist on circuits between Guam and N.W. Cape (Australia) and between Manila and N.W. Cape [McNamara, 1974a]. During daylight, both of these circuits support an Es-F mode with an MOF often in excess of 32 MHz (the upper limit of the oblique sounder) and a 2Es-F mode with a somewhat lower MOF. The Manila-N.W. Cape circuit appears to support the normal 2F and 3F modes as well, but the 2F mode may not exist on the Guam-N.W. Cape circuit because of Es screening.

Results from a sub-equatorial 1985 km path (East-West) between Sao Paulo (Brazil) and Tucuman (Argentina) for a TV (audio) frequency of 59.75 MHz, effective transmitter power in the direction of reception of 9 kW, reception antenna gain 6 dB (horizontal polarization, 14 m height) [Moro, 1984] show the following characteristics:

- high percentage of occurrence during night-time (2000-0100 local time);
- for field strength greater than 5 μV/m, the occurence is normally distributed with a maximum (70 h/month) in late spring and a minimum (1 h/month) in late autumn;
- for the period spring/summer, 60% of the days have been reported to have contacts lasting 2 h for field strength ⩾ 5 μV/m;
- percentage of hours/month decreases very rapidly with growing field strength, changing from one maximum in late spring to two maxima in early spring and early autumn (September and March) for field strength higher than 10 μV/m. Figure 5 summarizes observed hours/month reception as function of month and field strength level.

3.3.2 Mid latitudes

Preliminary studies in the South American sector indicate that the behaviour of oblique propagation via sporadic E in that sector can be acceptably described by the characteristics given below for the European sector.

Oblique-incidence pulse soundings between Greece and the Federal Republic of Germany (1700 km) [Reinisch, 1965] showed that the MOF was often determined by Es reflections from May to September, the average daytime occurrence (0600 to 1800 hours local time) being about 10% at 22 MHz decreasing to almost zero at 30 MHz. An examination of the oblique-incidence data obtained on the Ottawa-The Hague (5500 km) and Winnipeg-Resolute Bay (2800 km) circuits indicate that the sporadic-E mode at times controls the operational MUF, but sporadic-E layer propagation seldom occurs at frequencies greater than 30 MHz over these paths [Stevens, 1968].

Minullin [1988] and Minullin et al.[1988] have elucidated and analytically described the space-time variations of the limiting frequencies foEs for the middle latitudes, which makes it possible to calculate the probability of specific values of foEs for a selected latitude, season and time of day. Variations in the reflection coefficient for the Es layer in the case of oblique incidence have been obtained as a function of its limiting frequency of the sporadic-E layer and the critical frequency of the regular E layer.

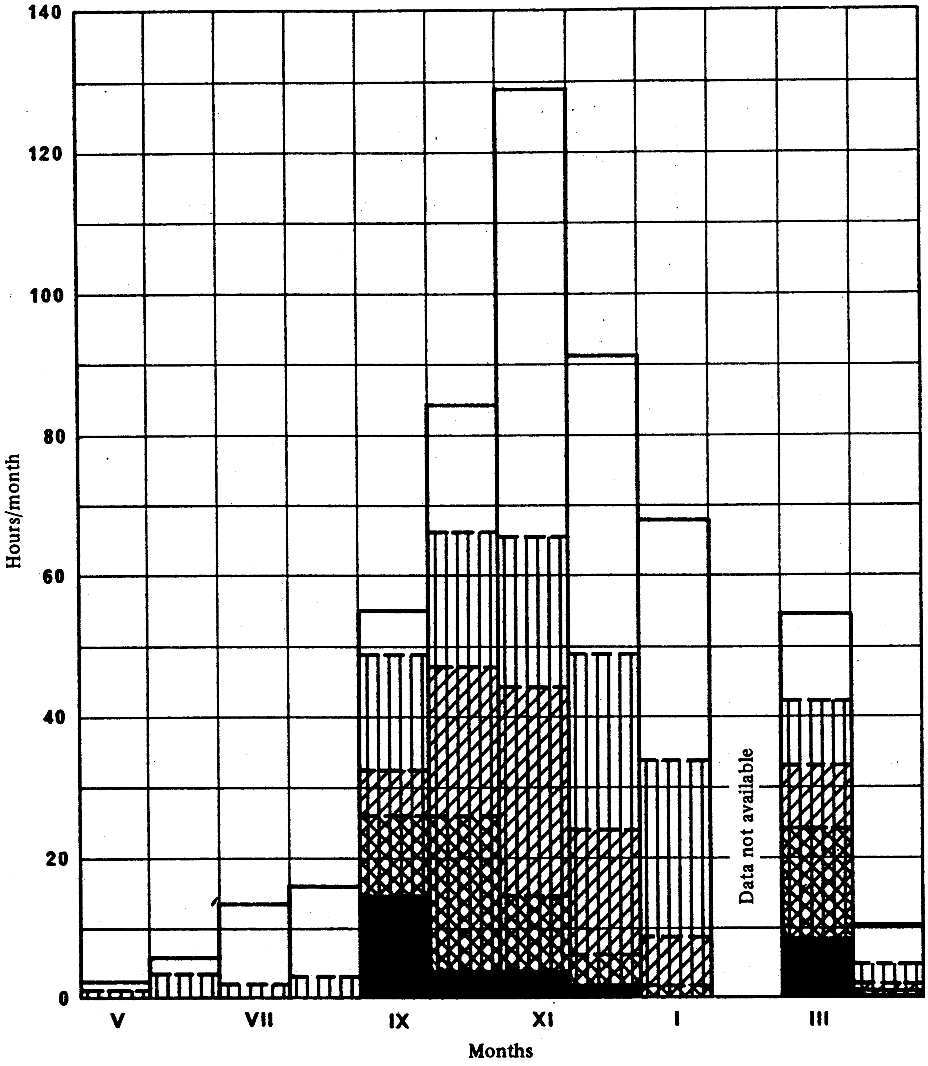


FIGURE 5 – *Cumulative number of hours/month for given field-strength intensity (1980-1981)*

□ E > 2 µV/m

▥ E > 5 µV/m

▨ E > 10 µV/m

▩ E > 20 µV/m

■ E > 50 µV/m

Roman numbers indicate month number (I = January)

Effective radiated power in the receiver direction: 9 kW

Since 1962, the EBU has recorded data on 23 paths [Lari *et al.*, 1967], varying in length between 900 and 2510 km, and which are situated in different locations in Western Europe. Daily measurements were taken at five frequencies in the range 41 to 59 MHz between 0800 and 2300 UTC from April to October of each year. The results may be summarized as follows:

- considerable year-to-year variation exists, differences in field strengths of up to 35 dB were observed;
- the month of maximum sporadic-E ionization varied between the end of spring and the end of summer;
- for a given path this month varied from year-to-year, and for a given year it changed for the various paths;
- studies of the variation in field strength with distance showed maximum field strengths (exceeded for 1% of the time) occurring at a distance of approximately 1400 to 1500 km; at these ranges the field strength exceeded for 5% of the time was about 15 to 30 dB lower. At 2500 km the corresponding field strengths were only 10 to 20 dB less than those at 1500 km. This result suggests that, at VHF, atmospheric refraction and the use of elevated antennae may extend the maximum range for one-hop ionospheric propagation beyond that normally experienced at lower frequencies.

The observations made during a complete solar cycle of 11 years, indicate that there is no simple long-term correlation between solar activity * and VHF propagation via Es. However, it became apparent that the yearly variations are rather regular and tend to be similar for different paths.

Table I shows the years when maxima and minima of the field strength were observed.

TABLE I

Path	*f* (MHz)	Field-strength maxima	Field-strength minima
Divis—Enköping	41·465	1964, 1966, 1971	1965, 1967/8
Divis—Châtonnaye	41·465	1964, 1966, 1971	1965, 1967/8
Meldrum—Enköping	58·215	1963/4, 1966	1965
Divis—Monte-Lauro	41·465	1964, 1968/9, 1971	1963, 1965/6, 1970

Analysis of several years of VHF recordings made at Aberystwyth, United Kingdom, of the received signal level on three frequencies, has allowed statistics to be compiled of the temporal behaviour of observed sporadic-E events [Edwards *et al.*, 1984]. The statistics relate to some nine years of recordings on 59.25 and 62.25 MHz, and to some six years of recordings on 77.25 MHz. The signals originate from broadcasting stations located mainly in central and eastern Europe at distances between 1000 and 2000 km and having effective radiated powers between 50 and 100 kW. Analysis has been confined to the time period 0600-2300 h UTC each day, there being few regular transmissions outside of these hours.

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* Sunspot-maximum: 1968-69; minimum: 1964-65.

Cumulative distributions, indicating the percentage of total duration of sporadic-E occurrence in summer time as a function of event duration, are shown in Fig. 6 for 62.25 MHz. These demonstrate that the total duration of all events is due largely to the duration of the longest events. At the 3 dB(μV/m) reference level, 75% of the total duration was contributed by events lasting longer than 5 min and at the 13 dB(μV/m) level, by events lasting longer than 4 min. Similar distributions were obtained for 59.25 and 77.25 MHz.

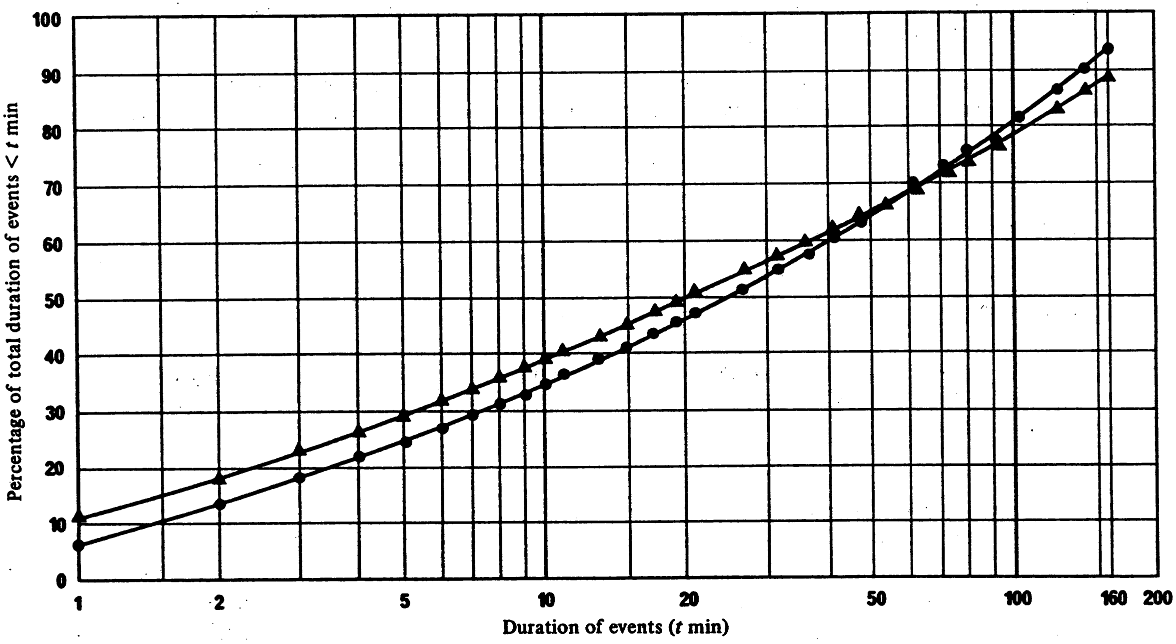


FIGURE 6 – *Cumulative percentage duration of events in summer time as a function of event duration for the two threshold levels observed at Aberystwyth at 62.25 MHz*

Threshold level (μV/m):
● 3 dB
▲ 13 dB

Figures 7 a) and 7 b) show the average total durations of sporadic-E events for the three frequencies plotted by month. The two figures relate to events exceeding field-strength levels of 3 dB(μV/m) and 13 dB(μV/m) respectively. A well-defined seasonal variation is apparent, showing sporadic-E as essentially a summer-time phenomenon, with very little activity between September and April. The greater occurrence of sporadic-E events on 62.25 MHz as compared with 59.25 MHz is a notable feature, contrary to the generally accepted frequency dependence of sporadic-E propagation. However, in a comparison of this kind, it is important to consider the geographical distribution of the transmission sources on each frequency as well as the number. Although fewer stations are to be found on 62.25 MHz than 59.25 MHz, they cover a considerably wider arc centred on Aberystwyth, and thus the number of potential propagation paths for 62.25 MHz might be expected to exceed that for 59.25 MHz.

Figures 7 a) and 7b) indicate that the greatest activity occurs in June, and the percentages of total time analyzed for which sporadic-E events were observed at each frequency are summarized in Table II.

TABLE II – *Maximum observed average time percentages of sporadic-E propagation*

	59.25 MHz	62.25 MHz	77.25 MHz
3 dB (μV/m)	8	12	2
13 dB (μV/m)	5	6	1.3

Figures 8 a) and 8b) show the average diurnal variation of sporadic-E event duration for the summer months May to August.

The distributions exhibit a twin peaked structure at 59.25 and 62.25 MHz, but only a single evening peak at 77.25 MHz. However, considerable variation was apparent in the diurnal patterns for individual months.

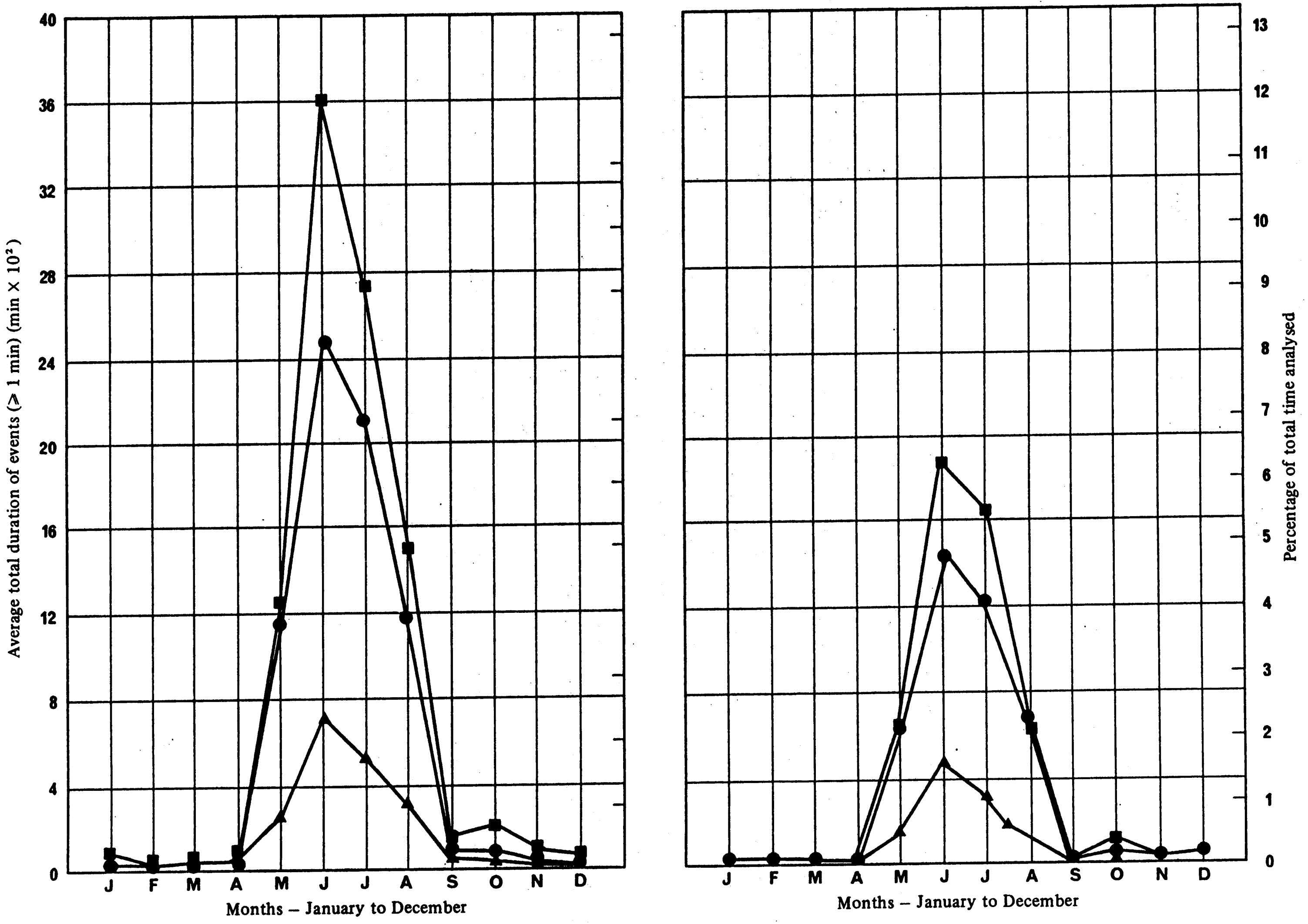
Distributions of the durations of events in summer-time exceeding the two field-strength thresholds for 62.25 MHz are shown in Fig. 9. The distributions indicate that:

– the events having the shortest duration occur most frequently; some 75% of the events observed above the 3 dB(μV/m) level had durations of less than 3 min, and 75% of those observed above the 13 dB(μV/m) level, less than 4 min;

– the stronger events (i.e. those observed above the 13 dB(μV/m) level), tend to be of longer duration than those observed above the lower level (3 dB(μV/m)).

Similar distributions were obtained for 59.25 and 77.25 MHz, revealing a slight frequency dependence with a tendency towards shorter events at the highest frequency. Further studies of event duration revealed enhancements in the numbers of the shorter events coincident with recurrent meteor showers, thereby indicating a contribution from propagation associated with long-lived meteor trails.

A similar distribution to that in Fig. 9 was obtained in a brief study undertaken by the EBU on three paths for June, 1971. The distribution was found to be largely independent of path length [EBU, 1976].



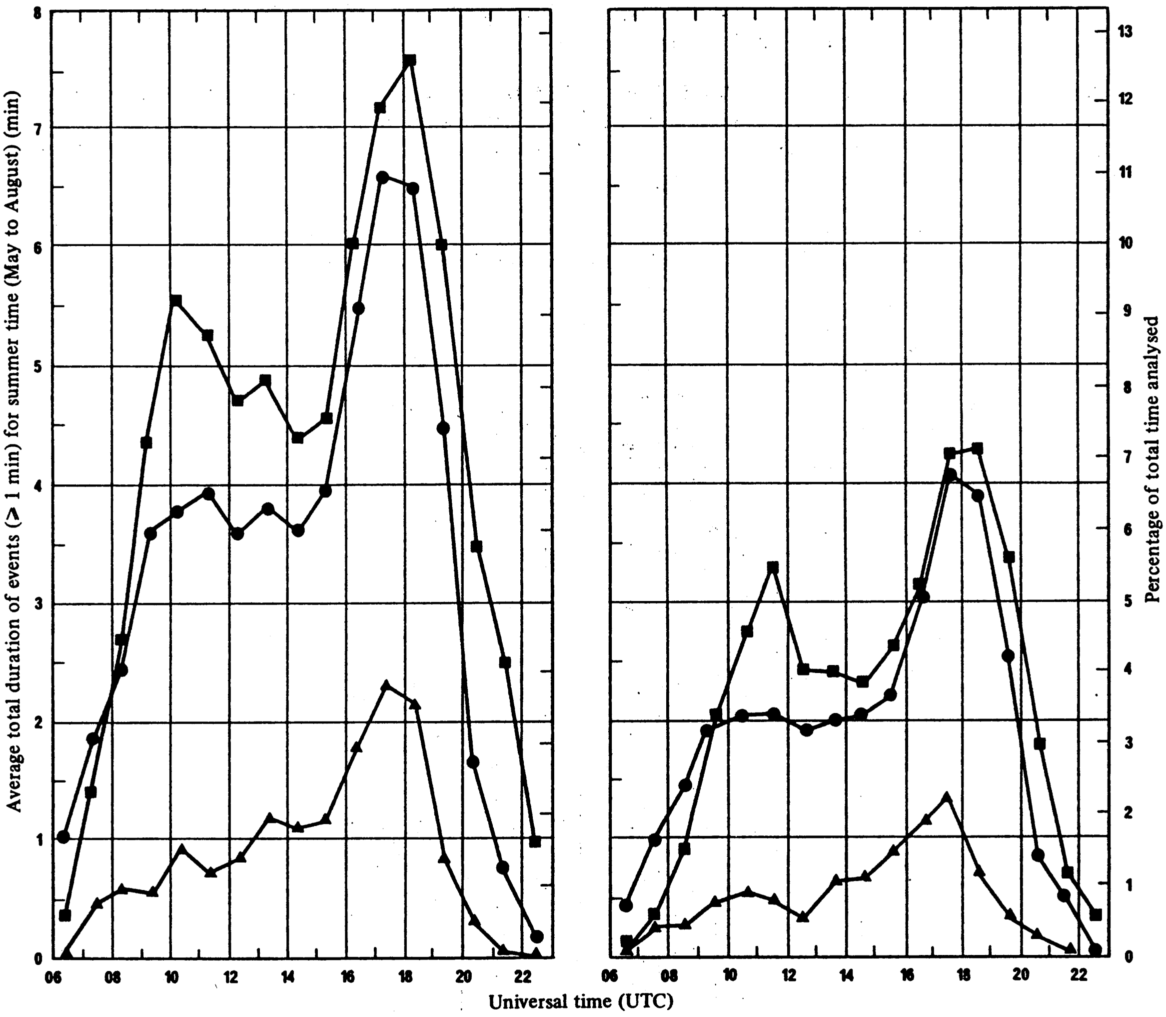
(a) 3 dB threshold level

(b) 13 dB threshold level

FIGURE 7 – *Seasonal variations of average total duration of events exceeding field strengths of 3 dB(μV/m) and 13 dB(μV/m)*

Frequency (MHz):

● 59.25 ■ 62.25 ▲ 77.25



(a) 3 dB threshold level

(b) 13 dB threshold level

FIGURE 8 – *Diurnal variations of average total duration of events exceeding field strengths of 3 dB(μV/m) and 13 dB(μV/m)*

Frequency (MHz):

● 59.25

■ 62.25

▲ 77.25

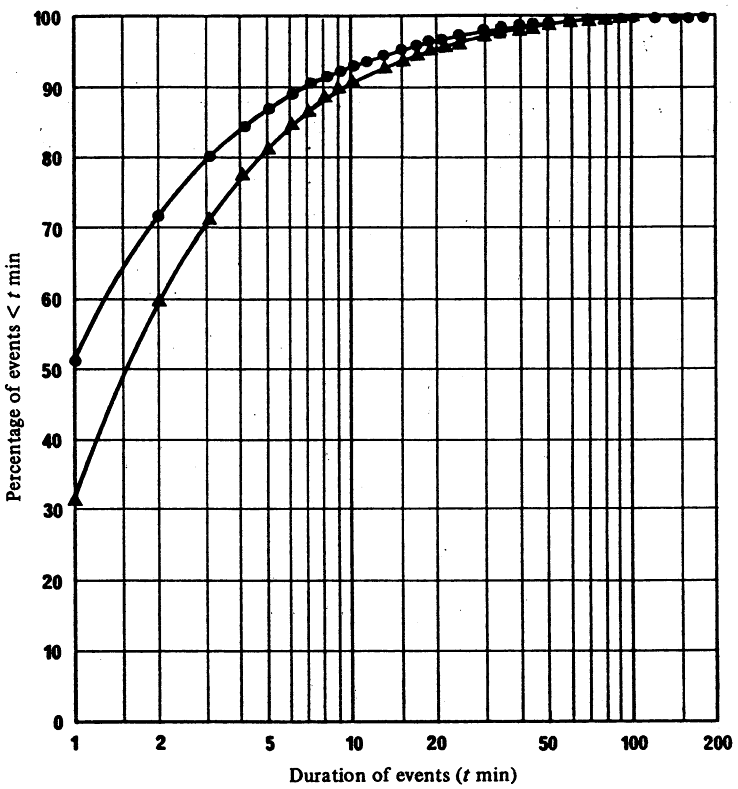


FIGURE 9 – *Cumulative distribution of events in summer time as a function of event duration for the two threshold levels observed at Aberystwyth at 62.25 MHz*

Threshold level (μV/m):
● 3 dB
▲ 13 dB

Detailed reports on amateur radio observations at frequencies as high as 144 MHz over Europe during occurrences of intense sporadic E have been summarized by Canivenc [1988].

3.3.3 High latitudes

Plasma frequencies as high as 14.9 MHz at 100 km altitude have been recorded near Fairbanks, Alaska [Wilson *et al.*, 1976]. For an assumed earth-curvature-limited secant factor of 5, this implies a MUF of 74.5 MHz. Sporadic-E propagation over polar paths as long as 5000 km have been observed with MUFs as high as 46 MHz [Hunsucker, 1979].

3.4 Sporadic-E propagation field strength estimation

The only comprehensive and continuing source of sporadic-E data is the world-wide network of ionosonde stations. It is important therefore to develop quantitative methods for estimating the oblique-incidence transmission characteristics from the vertical-incidence data. A consideration of this question for the United States is found in Davis *et al.* [1959].

A study of this problem in Japan has been carried out by Miya and Sasaki [1966] and by Miya *et al.* [1978]. Sporadic E is first classified by its reflection coefficient, Γ, as observed on VHF oblique-incidence circuits. The study suggests that if $\Gamma \leqslant 45$ dB, then the sporadic-E reflections are specular in nature, while if 45 dB $< \Gamma <$ 70 dB, a scattering mechanism is involved. Curves are available for calculating Γ in terms of the ratio f/foEs, where f is the transmission frequency in question and foEs is the vertical-incidence critical frequency of the ordinary wave for sporadic E taken from ionosphere observations. Estimates are available for both single-hop (0 to 2600 km) and two-hop (2600 to 4000 km) sporadic-E modes. An important feature of the method is the inclusion of antenna-to-medium coupling loss.

The Interim Working Party 6/8 has treated reflection loss of the sporadic-E signal applying the same analysis as used in the Japanese study described above. Many data for the temperate zone have been employed in the study including data of the EBU measurement campaign, 1962 to 1972 [EBU, 1976]. The IWP 6/8 method for calculating VHF sporadic-E signal strength at certain percentages of time of occurrence, is shown in Annex I to Recommendation 534. This method is applicable not only to VHF but is expected to be valid also for the upper half of the HF band if non-deviative D-region absorption is taken into account [CCIR, 1974-78].

A series of measurements was carried out in Italy in 1973 and 1974 of television transmitters at distances between 1000 km and 2500 km to determine the interfering field strength at about 55 MHz caused by sporadic-E layer propagation. The results showed a flat maximum of field strength at a distance of around 1800 km and proved to be in good agreement with that predicted by the method described by Miya *et al.* [1978].

A method has been developed in the USSR for calculating the horizontal Es layer inhomogeneity characterized by the angle of inclination of isolines of electron density based on vertical sounding data. It was used to calculate the focusing and defocusing effects of waves reflected from the Es layer [Kerblai and Kishcha, 1985].

Analysis of data from the equatorial belt shows that the percentage of time of Es occurrence is much higher for paths whose reflection point is in the equatorial belt and is found to exhibit an approximately linear relationship with the maximum frequency of vertical reflection instead of the well-known logarithmic relationship (Phillips law) accepted for middle latitudes.

Studies by the Max-Planck-Institute [Möller, 1963] using HF pulse transmissions with different transmitter powers over a 1965 km path in middle latitudes indicate the possibility that propagation by the sporadic-E layer may be power sensitive. This could result, for a 10 dB change in transmitter power, in modest differences (6 to 8%) is Es MOF. During the summer months, the power sensitivity appears to vary as a function of the time of day, indicating a possible correlation with the physical structure of the sporadic-E layer (see Report 255).

As a consequence of a study made in the USSR on oblique-incidence propagation over paths of about 1000 km in length and at frequencies of 4.5 to 40 MHz, with ionosondes near the path midpoints, the following conclusions were drawn [Kerblaï *et al.*, 1973, 1979]:

- the fading rate during Es propagation by specular reflection is slow (0.01 to 0.1 Hz), but increases when the scattering type of reflection sets in (0.05 to 0.4 Hz);
- while the secant law relating vertical-incidence values of foEs to oblique-incidence conditions is in satisfactory agreement in the HF band, it gives values 1.2 to 1.3 times too low at VHF;
- values of the focusing and defocusing effects during Es propagation are on average 2-4 dB and 5-7 dB respectively; in some cases (4% of the total number of Es cases), defocusing reaches values of 10-13 dB.

4. Main causes of interference to stations working at frequencies between 30 and 300 MHz

Cause of interference	Latitude zone	Period of severe interference	Approximate highest frequency with severe interference (MHz)	Approximate frequency above which interference is negligible (MHz)	Approximate range of distances affected (km)	Principal distinguishing features
Regular F-layer reflections	Mid	Day, equinox and winter, solar-cycle maximum	50	60	E-W paths 3000-6000 or N-S paths 3000-10 000	Occurrence broadly in accordance with regular-layer morphology
	Low	Afternoon to late evening, solar-cycle maximum	60	70		
Sporadic-E reflections	High	Night	70	90	500-4000	Principally during summer months in mid latitudes. Sudden onset and conclusion, beginning later and ending earlier with increase of operating frequency. Area concerned relatively small and mobile. Duration minutes or hours. No associated signal enhancements at short range
	Mid	Day and evening, summer	60	83-135 (1)		
	Low	Day	60	90		
Sporadic-E scatter	Low	Evening to midnight	60	90	Up to 2000	
Reflections from meteoric ionization	All	Particularly during showers	May be important anywhere in the range		Up to 2000	Signal bursts with durations from a fraction of a second to several minutes. Marked diurnal variation, maximum 0600 h local time, minimum 1800 h. Some activity present at all times, but considerable increases during predictable shower periods
Reflections from magnetic field aligned columns of auroral ionization	High	Late afternoon and night				Associated with geomagnetic disturbances, typically when local K-index reaches 5 or more. Characteristic rasping note due to multiple Doppler shifting. Normal duration a few hours, often afternoon to midnight.
Scattering in the F region	Low	Evening to midnight, equinox	60	80	1000-4000	
Special transequatorial effects	Low	Evening to midnight	60	80	4000-9000	Paths generally aligned symmetrically across the dip equator. Generally around equinoctial periods with regular occurrences. Strong signals. Refer to main text for further details.
Anomalous(2) tropospheric propagation	All	Any season or time	May extend into UHF	Generally beyond VHF band	Up to 2000 km	Associated with high atmospheric pressure. Effects cover wide area with a slow movement, gradual build-up and decline, with enhancement of normal signals at shorter ranges. May extend over several days. Comparable effects over a wide range of frequencies, usually beyond those affected by sporadic E.

(1) For 0.1% of the time during the hours 0800-2300 LT for May to August (111 min total) the following frequencies may be derived from the Annex I to Recommendation 534 for a distance of 1800 km and Γ = 30 dB for temperate zone:

Region A (Europe and North Africa)	83 MHz
Region B (North America)	93 MHz
Region C (Asia)	135 MHz
Region D (Average for northern hemisphere)	115 MHz

(2) See Recommendation 370.

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REPORT 251-5*

COMMUNICATION BY METEOR-BURST PROPAGATION

(Question 41/6)

(1959-1963-1966-1978-1982-1986-1990)

1. Introduction

Scattering from ionization caused by meteor trails provides a means of communication at HF and VHF. Experimental two-way telecommunications circuits have been operated with frequencies between 30 and 100 MHz over ranges up to 1300 km. The communication relies on bursts of propagation during the occurrence of meteor trails and supports data rates up to 100 bauds when averaged over several minutes.

Modern communication techniques, such as the use of mini-computers to carry out interactive operations between transmitting and receiving terminals, have made meteor-burst communication relatively more attractive for special applications where time delays of possibly a few minutes can be tolerated. Among such applications are the intermittent transmission of information to a central station from a large number of remote stations, transmissions to and from mobile terminals, and order-wire transmissions for engineering liaison in support of medium-length short-wave circuits.

The earliest indication that meteors could cause ionization in the upper atmosphere came from the observed correlation of trans-Atlantic HF signals with meteor showers [Pickard, 1931]. In 1943 the continuous monitoring of distant VHF stations in the USA showed that bursts of undistorted signals sometimes could be received at distances as great as 2200 km [Allen, 1948]. These bursts had durations up to one second and a diurnal variation in frequency of occurrence which correlated with the known incidence of visual meteors and with theoretical estimates.

Subsequent experiments used both back-scatter and forward-scatter techniques. Together with theoretical studies, a considerable amount of information on meteor-burst propagation was obtained by the mid-1950's. This activity culminated in an important set of papers which includes descriptions of two trial communication systems [Forsyth *et al.*, 1957; Vincent *et al.*, 1957].

The next decade saw further work which permitted better estimates to be made of the probable performance of a meteor-burst communication system. Summaries of the state-of-the-art appeared in the form of a book [McKinley, 1961] and an extensive review article [Sugar, 1964]. A more sophisticated experimental communication system employing automatic repeat transmission in the presence of errors (ARQ) and diversity reception gave a minimum transmission rate of 50 bauds over a 1000 km circuit [Bartholomé and Vogt, 1968]. Kokjer and Roberts [1986] have described networked meteor-burst communication system implementations. A historical perspective of meteor-burst communication system

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* This Report is brought to the attention of Study Group 3.