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IONOSPHERIC PROPAGATION IN EUROPE IN VHF TELEVISION BAND I

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Between 1962 and 1973, E.B.U. Working Party B carried out a series of measurements devoted to the propagation of VHF signals via sporadic-E layers; this propagation can occasionally cause serious interference to television reception in Band I.

This document, edited by Dr. P. Knight (B.B.C.), in collaboration with Messrs. L.F. Tagholm and C.P. Bell (B.B.C.) and Mr. Guido Lari (RAI), constitutes the final report on this series of measurements and has been submitted to the members of Working Party B for their approval. It is presented in two separate volumes, the first of which is devoted to the analysis of the results while the second contains the complete list of all the measured values so that they may possibly be used in other types of investigation.

This first volume describes the measurements, their analysis and the results obtained. These have enabled propagation curves to be drawn for Europe and a method of field-strength prediction to be devised. This method could be used in the planning of future VHF broadcasting services in Europe.

CHAPTER 1

Introduction

VHF transmissions in Band I (41 to 68 MHz) are sometimes received at distances well beyond the horizon, and often up to distances as great as 2500 km. The field-strengths occurring are often several orders of magnitude greater than those calculated for diffraction around the curvature of the Earth and may, on occasion, be comparable with free-space values.

Abnormal propagation to distances less than 1000 km is caused by refraction in the troposphere and is most likely to occur when the barometric pressure is high. Propagation to distances between 800 and 2500 km is due to reflection from clouds of intense ionisation which occur sporadically in the E layer of the ionosphere. In Europe the worst interference to television reception in Band I is that caused by sporadic-E propagation* in the summer months [1].

The characteristics of sporadic-E ionisation have been studied over many years and have been extensively described in the literature [2, 3, 4, 5, 6]. There are three main types of sporadic-E ionisation. *Auroral* sporadic-E occurs mainly at night within circular zones centred on the magnetic poles. Although the northern part of Scandinavia lies within the auroral zone, auroral sporadic-E has little or no effect on television broadcasting in Europe. Interference to television reception in Europe is caused by *temperate-zone* sporadic-E, which occurs during the day and early evening during the summer months. The third type is *equatorial* sporadic-E, which is confined to a small zone centred on the magnetic-dip equator and does not therefore affect propagation in Europe.

In order to assess the severity of interference caused by sporadic-E propagation in Europe, together with its dependence on factors such as distance and frequency, the E.B.U. organised a comprehensive series of measurements. These measurements, which extended over a period of eleven years in order to cover a solar cycle, have now been concluded. The measurement technique and the results obtained during the first six years have been described in document Tech. 3085 [7]. This document is the final report.

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* To improve the readability of the text, propagation via sporadic-E layers in the ionosphere is here termed "sporadic-E propagation".

CHAPTER 2

Organisation of the measurement campaign

Previous experience had shown that sporadic-E propagation causes most interference with television reception in Europe during daytime in the summer months. Interference is worst on the lowest frequencies in Band I but is seldom experienced at the highest frequencies. It is unlikely to occur at distances less than 500 km or greater than 2500 km. There was some evidence which suggested that it might be influenced by solar activity and by geographic latitude. The measurement campaign was therefore planned with these factors in mind and field-strength recordings were made throughout each day from April to October on a variety of paths.

Throughout the measurement campaign, normal service transmissions were received on simple aerials situated at heights typical of domestic installations; this arrangement was adopted because the object of the investigation was to study the effect of sporadic-E propagation on television reception rather than to study the sporadic-E layer itself. It is hoped, however, that the results of the investigation will also add to our knowledge of the behaviour of the ionosphere.

1. Choice of paths

A trial measurement campaign was organised in 1961, when the 41.5 MHz sound transmission from Crystal Palace (United Kingdom) was recorded at four locations on the European mainland, at distances between 640 and 1900 km. Having demonstrated that signals propagated via the sporadic-E layer could be measured successfully, a more comprehensive series of measurements was organised in subsequent years. Initially, only the transmitters at Divis and Meldrum, situated in the northern part of the United Kingdom were recorded. In 1965, however, the measurements were extended to include the transmitters at Limoges and Carcassonne in France, and a special transmitter was installed at Monte Sambuco in Italy to provide a transmission on an additional frequency. The geographical arrangement of the paths was then as shown in *Fig. 1*, and this arrangement continued until 1972, when the measurements were discontinued. Full details of all the paths used for measurements during the period 1962 to 1972 are given in *Table 1*.

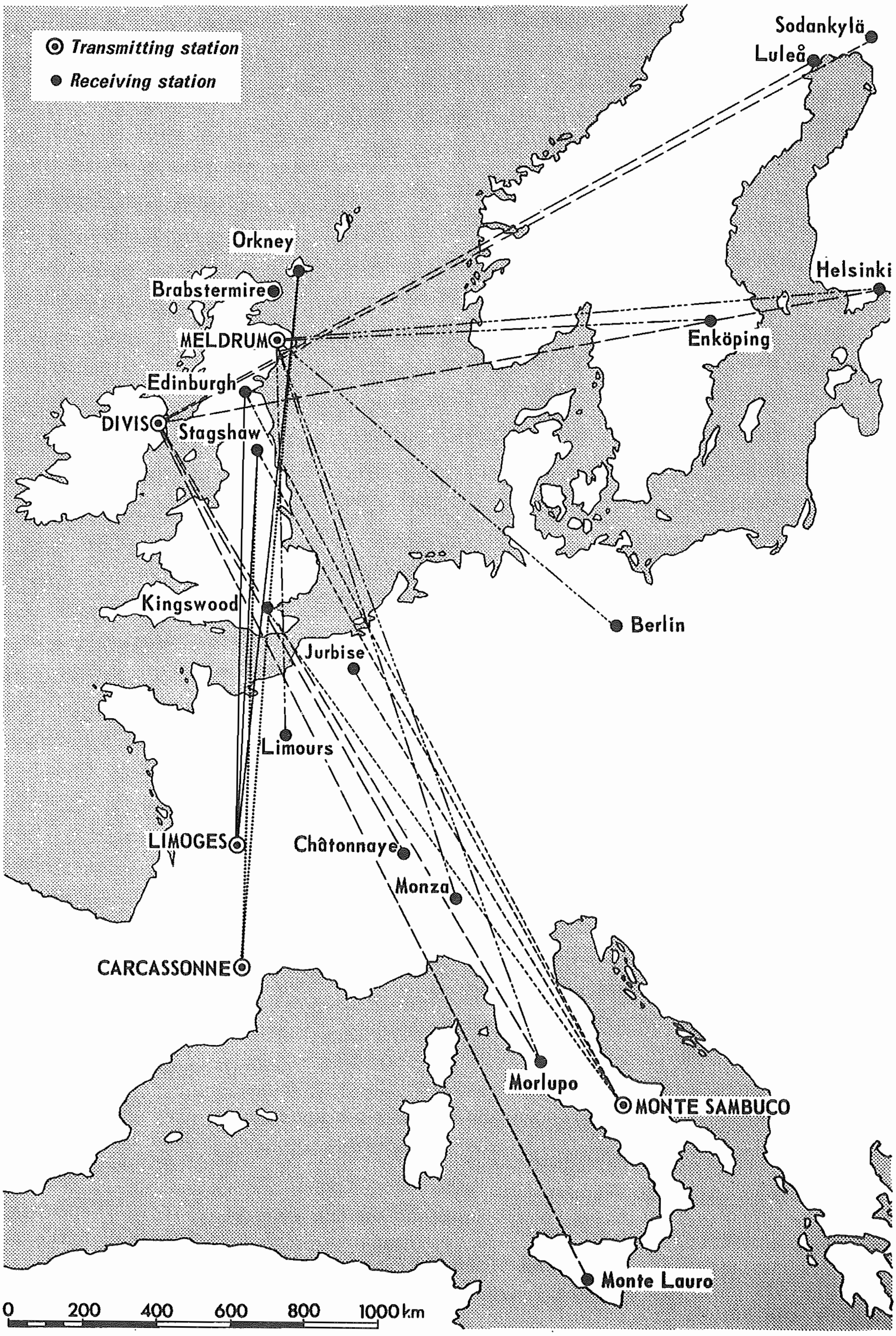

Fig. 1. - Propagation paths

The measurements undertaken in 1965 at Brabstermire were next made at Orkney.

Table 1 - Propagation paths

Transmitter, frequency and polarisation	Receiver	Path length (km)	Radiation angle (degrees)	Correction factors (dB)		Polarisation received	Measurement period
				e.r.p. factor	v.r.p. factor		
Limoges 41.28 MHz H	Stagshaw	1060	8.7	18.5	17.8	H	1965-1972
	Edinburgh	1180	7.3	18.0	18.2	H	1965-1972
	Brabstermire	1470	4.8	18.5	4.9	H	1965
	Orkney	1500	4.6	18.5	4.9	{ H V	1966-1972 1970-1971
Divis 41.465 MHz H	Châtonnaye	1260	6.6	5.0	2.6	H	1962-1972
	Monza	1470	4.8	5.0	1.2	H	1962,1963
	Enköping	1490	4.7	5.0	1.2	H	1962-1972
	Morlupo	1930	2.1	5.0	0.2	H	1964-1972
	Helsinki	1940	2.0	5.0	0.2	H	1966-1972
	Luleå	1950	2.0	5.0	0.2	H	1965-1972
	Sodankylä	2220	0.9	5.0	0	H	1965-1972
	Monte Lauro	2510	0.1	5.0	0	H	1962-1972
Monte Sambuco 49.30 MHz H	Jurbise	1320	6.0	2.0	0	H	1965-1972
	Kingswood	1590	4.0	2.0	0	{ H V	1965-1972 1966-1967
	Stagshaw	1950	2.0	2.0	0	H	1965-1972
	Edinburgh	2070	1.4	2.0	0	H	1965-1972
Carcassonne 54.43 MHz V	Kingswood	900	11.0	13.0	15.2	{ V H	1965-1972 1966-1967
	Stagshaw	1330	5.9	13.0	1.8	V	1965-1972
	Brabstermire	1730	3.2	12.5	-0.4	V	1965
	Orkney	1760	3.0	12.5	-0.4	{ V H	{ 1966-1970, 1972 1970-1971
Meldrum 58.215 MHz H	Limours	1010	9.4	6.5	3.9	H	1965-1972
	Berlin (West)	1130	7.9	6.0	2.6	H	{ 1963-1968 1970-1972
	Enköping	1150	7.7	1.0	2.6	H	1962-1972
	Monza	1530	4.4	6.0	0.9	H	1962-1966
	Helsinki	1600	4.0	1.0	0.7	H	1966-1972
	Morlupo	1990	1.8	6.5	0.2	H	1967-1972

H : horizontal   V : vertical

Table 1 shows that the highest frequency employed was about 58 MHz; although Band I extends to 68 MHz, experience had shown that sporadic-E propagation seldom occurs at the highest frequencies in the Band. Path lengths ranged from 900 to 2510 km, the latter distance corresponding to the extreme range of 1-hop propagation via the E layer. All the transmitters except Carcassonne radiated horizontal polarisation; the polarisation of the wave incident on the ionosphere is not thought to be an important factor at VHF. Of more importance is the polarisation of the received signal. If the polarisation of the transmitted signal were preserved, some discrimination against unwanted signals could be achieved by using a receiving aerial intended for the orthogonal polarisation, and advantage could be taken of this fact in planning networks of co-channel transmitters. Simultaneous recordings of both the transmitted and orthogonal polarisation were therefore made over a number of paths (indicated in *Table 1*) to see whether any advantage can be gained from polarisation discrimination.

Table 1 also gives the radiation angle for each path; this is the angle of elevation at the path terminals for single-hop propagation via a spherical ionosphere. The radiation angles should be regarded as median values; variations in reflection height will cause an angular spread of about ± 1°. The ionosphere was assumed to have a median height of 105 km for paths shorter than 2000 km but for greater distances the median height was increased progressively to 120 km, because the curvature of the Earth obstructs waves reflected from the lower part of the height distribution and so increases the median reflection height for the waves which propagate*. The elevation angles were derived from curves which take atmospheric refraction at the terminals into account; these curves were calculated for the C.C.I.R. at the Swedish National Defence Research Institute.

The correction factors in *Table 1* were used in the analysis of the results and are discussed in Chapters 3 and 4 (§ 6).

2. Characteristics of the transmitting and receiving stations

Details of the transmitting stations are given in *Table 2*. Normal service transmissions were measured except at Monte Sambuco, where the transmitter radiated plain carrier interrupted periodically for identification purposes. The frequencies quoted for the other four stations are those of their sound transmitters, which were recorded in preference to the vision transmitters because of their better carrier-amplitude stability. At Divis, Meldrum and Limoges, the sound frequencies were changed by 35 kHz from the normal channel frequencies to enable receivers to discriminate against signals from other stations sharing these channels.

Table 2 - Characteristics of transmitting stations

Transmitting station	Country	Geographical coordinates	Frequency and polarisation	e.r.p. (1) (kW)	Height of aerial above ground (m)	Height of station above sea level (m)
Limoges	France	45°40'N, 1°04'E	41.28 MHz, H	63-72	200	536
Divis	U.K.	54°36'N, 6°00'W	41.465 MHz, H	2.9-4.2	145 127 (2)	365
Monte Sambuco	Italy	41°32'N, 15°05'E	49.30 MHz, H	1.6		975
Carcassonne	France	43°25'N, 2°27'E	54.43 MHz, V	17-20	65	1210
Meldrum	U.K.	57°23'N, 2°24'W	58.215 MHz, H	1.1-4.3	141	245

(1) e.r.p. at zero elevation angle, in directions of receiving stations.

(2) original aerial at 145 m replaced by aerial at 127 m in December 1975.

* The relationship between the radiation angle and the path length assumed here is shown in *Fig. 13*.

Table 2 gives the effective radiated powers (e.r.p.), in the horizontal plane, in the directions of the receiving stations. All the service aerials have a certain amount of horizontal directivity which was allowed for when the results were analysed. The Monte Sambuco aerial, however, was highly directional, with its main lobe oriented towards the receiving stations and a minimum directed towards Bastia (France) to prevent interference.

Fig. 2 shows the vertical radiation patterns (v.r.p.) of the four service aerials together with the elevation angles given in *Table 1* for the various paths. The v.r.p. of the Monte Sambuco aerial is not shown because it had negligible vertical directivity at elevation angles less than 15°.

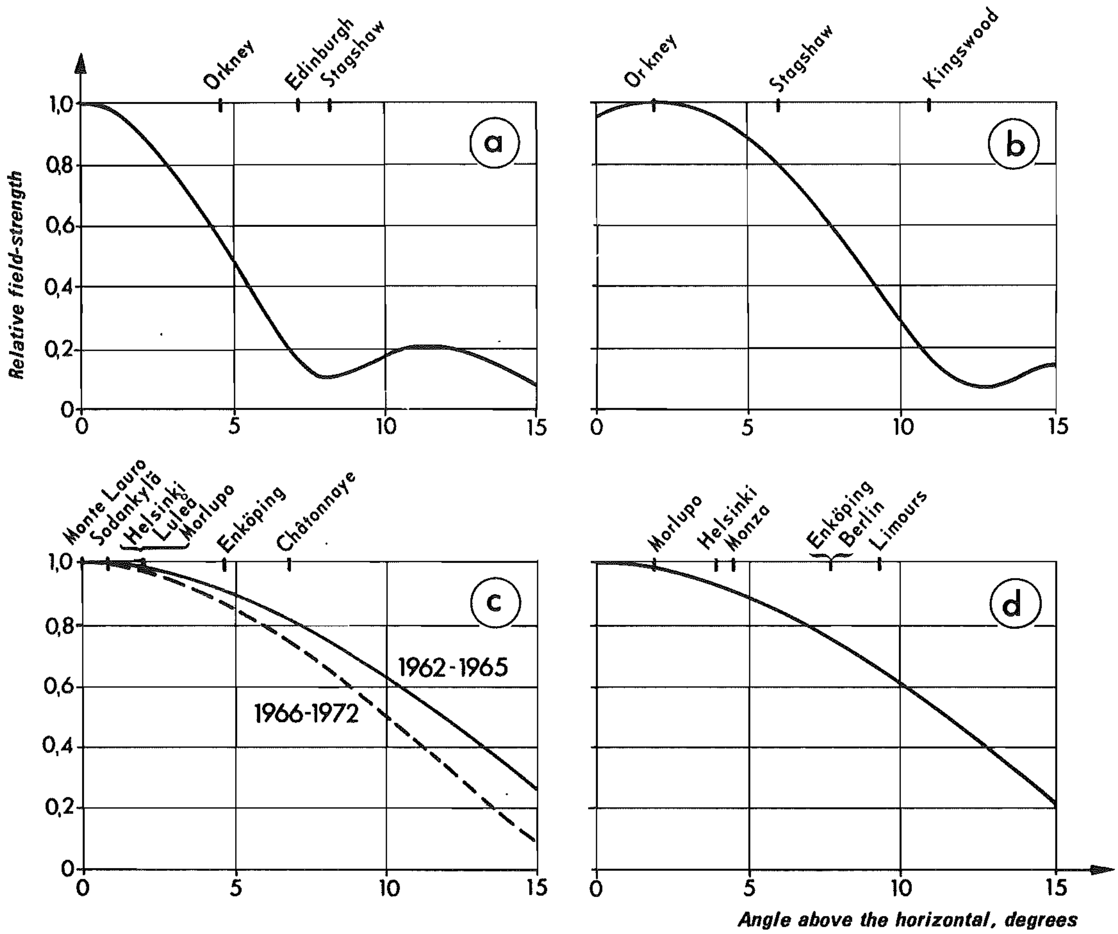

Fig. 2. - Vertical radiation patterns of transmitting aerials.

a) Limoges ***b) Carcassonne***
c) Divis ***d) Meldrum***

Fig. 2 shows that, on some paths, the effective powers radiated towards the ionosphere are considerably less than the e.r.ps in the horizontal plane. The difference between the two e.r.ps is particularly large on the Limoges-Edinburgh and Limoges-Stagshaw paths. To study the effect of vertical directivity, a low-gain aerial radiating at 41.01 MHz was installed at Limoges and both transmissions from Limoges were recorded simultaneously at Stagshaw and Orkney during 1971 and 1972. Helicopter measurements showed, however, that the v.r.p. of the low-gain aerial at Limoges was very badly distorted by the mast structure and its stay wires and consequently the results of the comparison were inconclusive.

At Divis the original transmitting aerial was replaced by a new aerial in December 1965. A slight reduction in aerial height was accompanied by slight increases in e.r.p. and vertical directivity. These small changes are unlikely to have affected the continuity of the measurements.

Table 3 gives details of the geographical locations of the receiving stations and the organisations which were responsible for them.

Table 3

Characteristics of receiving stations

Receiving station	Country	Geographical coordinates	Organisation responsible
Jurbise	Belgium	50°32'N, 3°56'E	E.B.U.
Sodankylä	Finland	67°22'N, 26°39'E	YLE
Helsinki	Finland	60°10'N, 25°03'E	YLE
Limours	France	48°40'N, 2°05'E	O.R.T.F.
Berlin (West)	Germany	52°34'N, 13°18'E	D.B.P.
Monza	Italy	45°36'N, 9°16'E	RAI
Morlupo	Italy	42°09'N, 12°29'E	RAI
Monte Lauro	Italy	37°06'N, 14°50'E	RAI
Enköping	Sweden	59°35'N, 17°03'E	P.T.T.
Luleå	Sweden	65°36'N, 22°07'E	P.T.T.
Châtonnaye	Switzerland	46°46'N, 6°57'E	P.T.T.
Kingswood	United Kingdom	51°17'N, 0°13'W	B.B.C.
Stagshaw	United Kingdom	55°02'N, 2°01'W	B.B.C.
Edinburgh	United Kingdom	55°55'N, 3°11'W	B.B.C.
Brabstermire	United Kingdom	58°37'N, 3°10'W	B.B.C.
Orkney	United Kingdom	58°55'N, 2°56'W	B.B.C.

3. Receiving equipment

Conventional receivers and pen recorders are unsuitable for sporadic-E propagation measurements because they are unable to record a sufficiently wide range of signal levels when left unattended; signals propagated via the sporadic-E layer may vary by as much as 60 dB. A further difficulty arises in Europe because of the large number of transmissions and the need to distinguish between them. Special receiving equipment therefore had to be made.

The receiving equipment satisfied the following main requirements:

- the installations were capable of continuous unattended operation;
- the receivers were crystal controlled;
- the selectivity was sufficient for protection against interfering transmissions, independent of any protection obtained with a directional receiving aerial;
- the sensitivity was sufficiently high for measuring signals of 1 μV/m or less;
- the output law was logarithmic, with a scale range of at least 40 dB;
- signal-strength was recorded on a pen-recorder adjusted for a chart speed of about 60 mm per hour, or on automatic recorders;
- the required time-constant of the apparatus was of the order of one minute.

The equipment used at the E.B.U. Receiving and Measuring Station at Jurbise (Belgium) consisted of a Collins communication receiver for medium and short waves, preceded by a crystal-controlled mixer stage and followed by a Siemens recording meter. Only the mixer, which converts the received signal to a frequency of 10.7 MHz, was specially made for these measurement campaigns. The receiver, tuned to the output frequency of the mixer, served as a selective and stable intermediate frequency amplifier having the four possible frequency-response characteristics shown in *Fig. 3*. The recording meter was energised by the DC voltage of the automatic gain control (proportional to the input signal), suitably amplified. The equipment was periodically calibrated with the aid of a Marconi signal generator.

The equipment used at Limours also consisted of a Collins MF/HF receiver, preceded by a crystal mixer, constructed by the O.R.T.F., which converted the received signal to a signal at 9.789 MHz. A 4-element Yagi aerial was used, giving a gain of 6.5 dB, a front-to-back ratio of 23 dB and a beam-width of 55°. It was installed 10 m above ground level.

The equipment installed by the RAI in Italy at the stations at Monza, at Morlupo (near Rome) and Monte Lauro (near Catania) was specially built for the measurement campaigns. It consisted of valve receivers with crystal-controlled oscillators for double-frequency conversion, incorporating two intermediate frequency amplifiers. The first was tuned to a frequency of 10.7 MHz and the second to 467 kHz. The receiver output (either logarithmic or linear) was applied as a DC voltage to a CGS pen-recorder having a chart speed of 60 mm per hour.

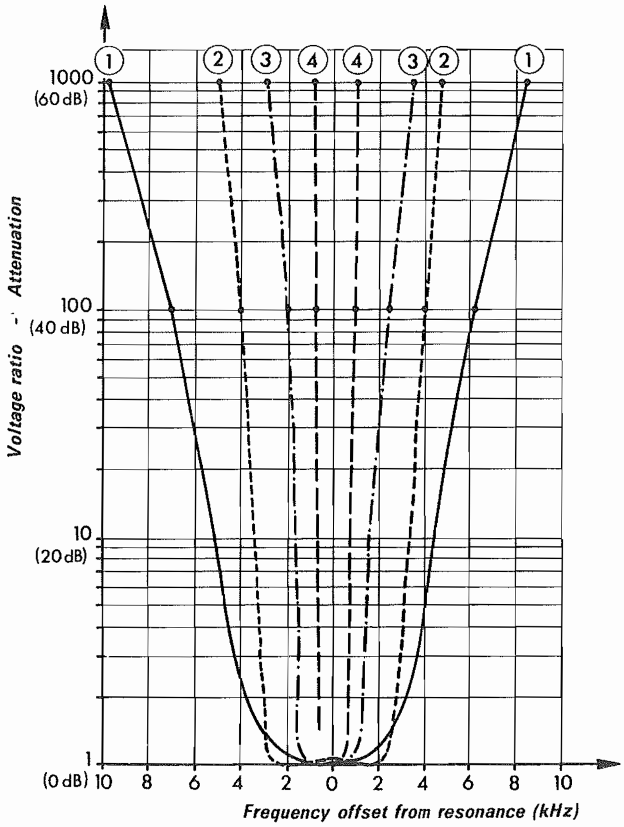

Fig. 3.* - *Frequency response of receiving equipment at the E.B.U. Receiving and Measuring Station at Jurbise (Belgium).

(1) ***Normal IF response***
(2) ***With a 6-kHz filter***
(3) ***With a 3-kHz filter***
(4) ***With a 1-kHz filter***

Each receiver was periodically calibrated with a signal generator by specialist staff. The frequency stability of the receivers was ± 1 part in 10^5. The bandwidth was 5 kHz at -6 dB relative to peak response and 26 kHz at -70 dB.

The B.B.C. equipment in the United Kingdom was specially designed for unattended operation over long periods. It consisted of crystal-controlled solid-state receivers having a single intermediate frequency of 270 kHz. The response of the amplifier was practically constant to about ± 5 kHz relative to the centre frequency, but fell by 45 dB at ± 20 kHz. The frequency stability of the local oscillator was ± 2 parts in 10^5. A DC voltage proportional to the logarithm of the signal input was obtained with a multiple detector shown schematically in *Fig. 4*. The output of the detector was then applied to a pen-recorder. Although the receivers were designed to have a stability better than ± 1 dB between -10°C and +45°C, it was usual for several receivers to be mounted in a single temperature-controlled case to ensure gain stability.

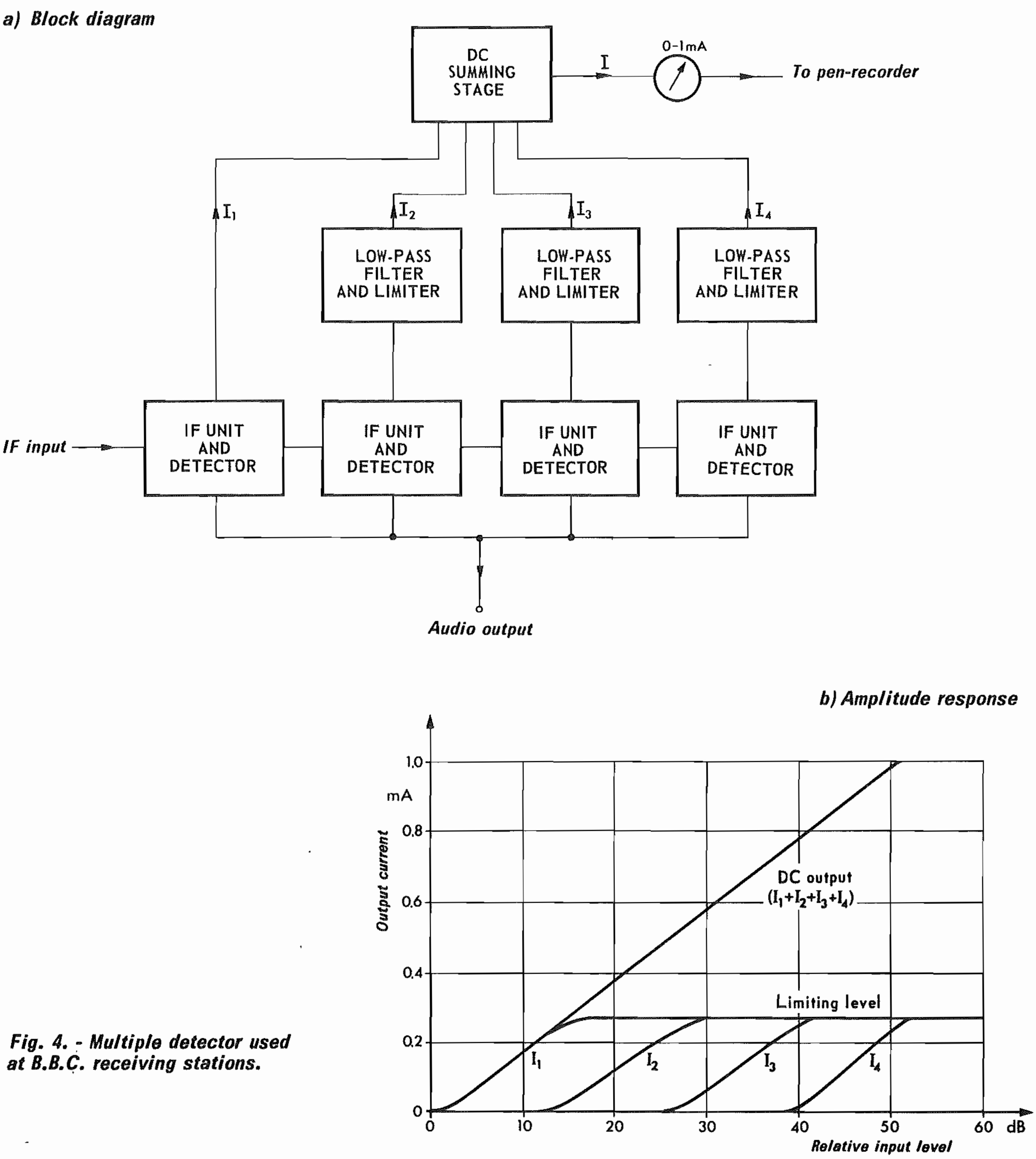

Fig. 4. - Multiple detector used at B.B.C. receiving stations.

The receiving equipment was installed in television stations such as Monte Lauro, or in measuring centres such as Enköping, Jurbise and Monza, or outside such centres, in special huts, as at Kingswood Warren. The receiving aerials were Yagi-type, or simple dipoles with reflectors. Their purpose was to increase the sensitivity of the equipment (the gain of a four-element Yagi aerial is about 6 dB), but also in many cases to discriminate against unwanted signals. They were usually mounted at heights of about 10 m; this ensured that the results were valid for domestic receiving installations.

CHAPTER 3

Method of analysis

Measurements of signals propagated via the sporadic-E layer must be analysed statistically because of the random nature of their occurrence. The outcome of the analysis is therefore either a statement of the percentage of time that a given field-strength is exceeded, or a statement of the field-strength which is exceeded for a specified percentage of a given period. The second alternative is preferred for planning purposes; the method used to extract this information from the field-strength recordings is described in this section.

Continuous recordings were made every day between 0800 and 2300 GMT from April to October each year. In analysing the charts, the time during which the field-strength exceeded certain specified levels, usually differing by 10 dB, was determined for each day. The total time that each level was exceeded during complete months was then calculated, and the results expressed as percentages of the total recording time for that month. A graph of field-strength against percentage time was then plotted and the field-strengths exceeded for specified time percentages derived by interpolation. Finally, the field-strengths were standardised to an e.r.p. of 1 kW by subtracting the e.r.p. correction factors given in *Table 1*. Thus the results finally tabulated are the field-strengths which would have been exceeded for certain percentages of the actual recording times, if the transmitting stations had radiated with an e.r.p. of 1 kW in the horizontal plane, in the directions of the receiving stations.

Graphs which illustrate the results obtained in the earlier years of the measuring campaign are contained in document Tech. 3085 [7] and these graphs give a good indication of the trends which were observed throughout the eleven years of measurement. The complete results of the measuring campaign, in the form of tables and graphs, are contained in Volume II of this document. The final results give the field-strengths which were exceeded during stated percentages of the time-period 0800 to 2300 GMT. The same field-strengths would be exceeded for somewhat lower percentages of the complete 24-hour period.

The basic analysis described above, which was performed for all paths and years, was supplemented by more detailed analyses on certain paths in order to study particular aspects of sporadic-E propagation. Details of these supplementary analyses are given under the appropriate headings in Chapter 4.

CHAPTER 4

Discussion of results

Sufficient results were obtained over the eleven-year period to give good indications of all the temporal variations to which sporadic-E propagation in Europe is subject. The results also enable propagation curves for Europe to be drawn. The conclusions which can be drawn from the measurements are described in detail in this chapter.

1. Influence of solar activity

Although the measurement campaign was continued for eleven years in order to cover a complete sunspot cycle, recordings were made on only four paths for the entire period. When the month-by-month analyses of the measurements are plotted, as in the second part of Volume II, solar-cycle variations tend to be obscured by the much larger seasonal variations. To minimise seasonal effects, therefore, the total times each year during which certain specified field-strengths were exceeded during the five-month period May to September were calculated from the recorder chart analysis and expressed as percentages of the total recording time (0800 to 2300 GMT, each day). Measurements made on seven paths which had been studied for the greater part of the solar cycle were analysed in this way*. For each path the field-strength level chosen for analysis was that normally exceeded for between 0.5 and 5 % of the total time.

The correlation between the percentage time each year that the chosen level was exceeded and the average sunspot number for the period is illustrated in *Fig. 5*. Regression analyses were performed for each path, with sunspot number as the independent variable but the regression was found to be statistically significant on only three paths; regression lines for these paths are shown in *Fig. 5*.

The results show a slight tendency for propagation via the sporadic-E layer to occur less frequently when solar activity is greater but the results are not conclusive. For planning purposes, therefore, it is proposed that no allowance should be made for solar activity.

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* Details of the paths are given below *Fig. 5*. Measurements made between 1962 and 1964 on the Meldrum-Enköping path have been excluded because they differ from subsequent measurements by about 20 dB, and detailed examination of the analysis suggests that they are in error.

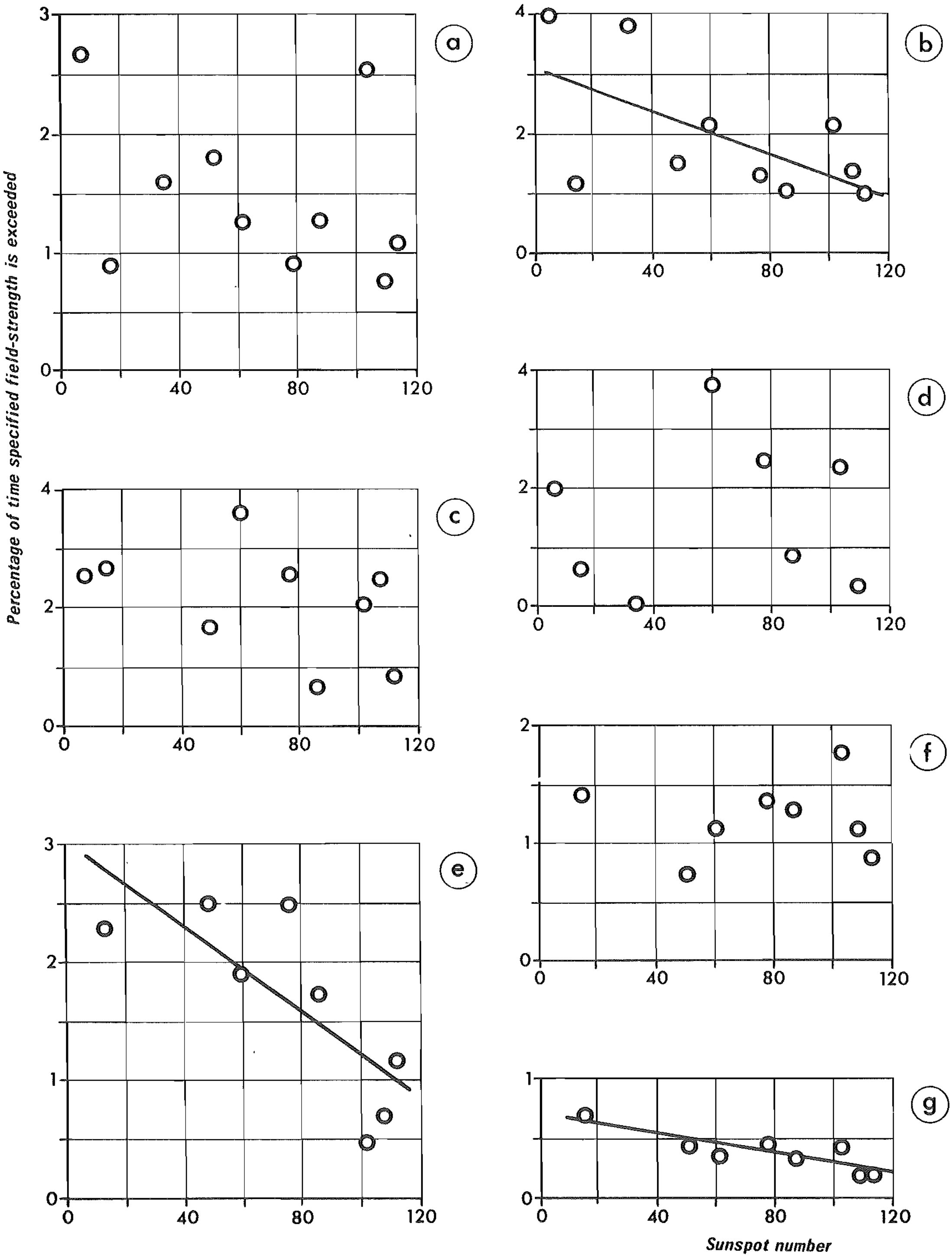

Fig. 5. - Correlation with solar activity.

a) Divis - Châtonnaye, 41.465 MHz, 25 dB(μV/m)
b) Divis - Enköping, 41.465 MHz, 15 dB(μV/m)
c) Divis - Morlupo, 41.465 MHz, 25 dB(μV/m)
d) Divis - Monte Lauro, 41.465 MHz, 5 dB(μV/m)
e) Monte Sambuco - Kingswood, 49.30 MHz, 18 dB(μV/m)
f) Carcassonne - Stagshaw, 54.43 MHz, 7 dB(μV/m)
g) Meldrum - Enköping, 58.215 MHz, -1 dB(μV/m)

The field-strengths quoted above are the levels (reduced to 1 kW e.r.p.) for which 5-month percentage times were calculated.

2. Seasonal variation

Before the measuring campaign started it was known that interference caused by sporadic-E propagation in Europe is most severe in the summer months and seldom occurs during the winter. It was therefore decided that recordings should be made only during the months of April to September. This procedure was justified by continuous recordings of Limoges and Carcassonne which were made throughout the winter of 1968-1969 at Orkney without any appreciable signal being observed.

The month-by-month plots of the measurement results contained in the second part of Volume II show that the seasonal variation changes considerably from one year to another. To obtain some indication of the average variation, field-strengths exceeded for a convenient time percentage were extracted from the tables of the first part of Volume II and grouped according to month. Median field-strengths for each month were then determined; these are the values exceeded by half of each group of field-strengths. Results obtained for four paths are shown in *Fig. 6*, the circles

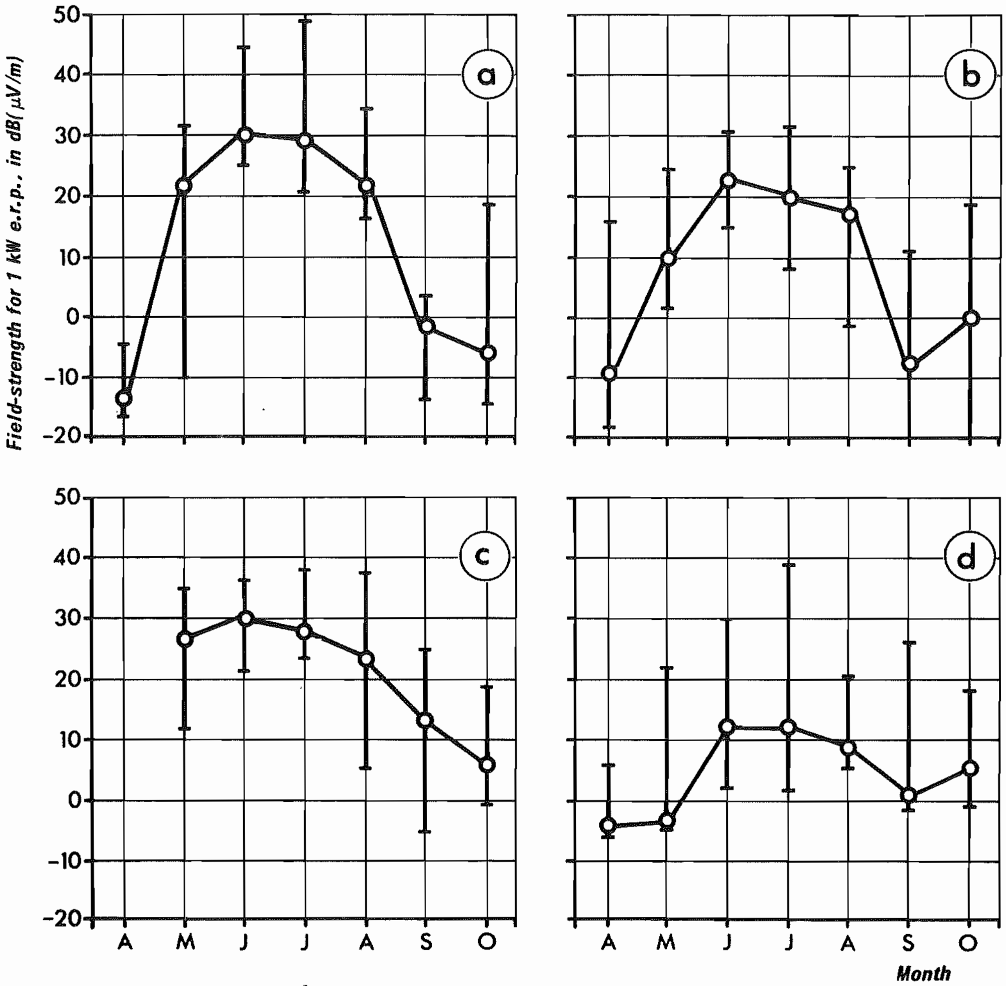

Fig. 6. - Seasonal variation.

a) Divis - Châtonnaye, 41.465 MHz, 1 % of the time
b) Divis - Sodankylä, 41.465 MHz, 0.1 % of the time
c) Monte Sambuco - Stagshaw, 49.30 MHz, 0.1 % of the time
d) Meldrum - Enköping, 58.215 MHz, 0.1 % of the time

indicating the median values, and the vertical lines indicating the range between the largest and smallest field-strengths in each group. These paths, whose characteristics are recalled in the caption of *Fig. 6*, were chosen so as to include a range of frequencies and directions of propagation. The measurements analysed in this way covered the period 1965 to 1972.

Fig. 6 shows that, on average, the incidence of sporadic-E propagation is slightly greater in June than in July although the highest field-strengths are observed in July. Thus June and July can be regarded equally as the months when most interference due to sporadic-E propagation is likely to occur in Europe. An interesting feature shown by *Fig. 6* is that field-strengths observed in October are sometimes greater than those occurring in the previous month.

3. Diurnal variation

In temperate latitudes, sporadic-E propagation occurs most frequently during the day. To see whether propagation varies during the hours of daylight, all the measurements made from 1965 to 1967 were analysed by dividing the day into four roughly equal periods. As significant differences between these four periods were found, some of the measurements made in 1968, and most of those made in 1969, were analysed in one-hour time blocks. This analysis, which was additional to the normal analysis described in Chapter 3, was confined to one field-strength level.

Fig. 7 shows results for both years for four paths. Each point represents the total time that the measured field-strength exceeded 3 μV/m (before correction to 1 kW e.r.p.) between 1st May and 31st August, during each of the 15 one-hour periods during which measurements were made. Vertical lines indicate noon at the path mid-point. Nearly all the curves show a tendency for propagation to occur most frequently at noon and again in the late afternoon, with a minimum at about 1500 GMT. Comparison of *Figs. 7a* and *7b* shows that the diurnal variation on the high-latitude path from Divis to Helsinki is similar to that at lower latitudes; the variation on the more northerly Divis-Sodankylä path was also similar, indicating that temperate-zone sporadic-E propagation still predominates at the southern boundary of the auroral zone. On the higher frequencies (*Figs. 7c* and *7d*) the diurnal variation was again similar although the total time that the specified field-strength was exceeded was somewhat less than at the lower frequencies.

In all, 24 curves of the type shown in *Fig. 7* were derived from the analysis*. As no systematic influence of latitude, path length or frequency could be discerned, all the results of the analysis were combined in the single diurnal-variation curve shown in *Fig. 8*. Before combining the individual results, each individual hourly value (as plotted in *Fig. 7* was divided by the average value for the path, calculated from the 15 individual values. Normalised values for specific times relative to local time at the path mid-point were then derived by linear interpolation.

* Three paths were excluded because insufficient sporadic-E propagation was observed to give a reliable indication of the diurnal variation.

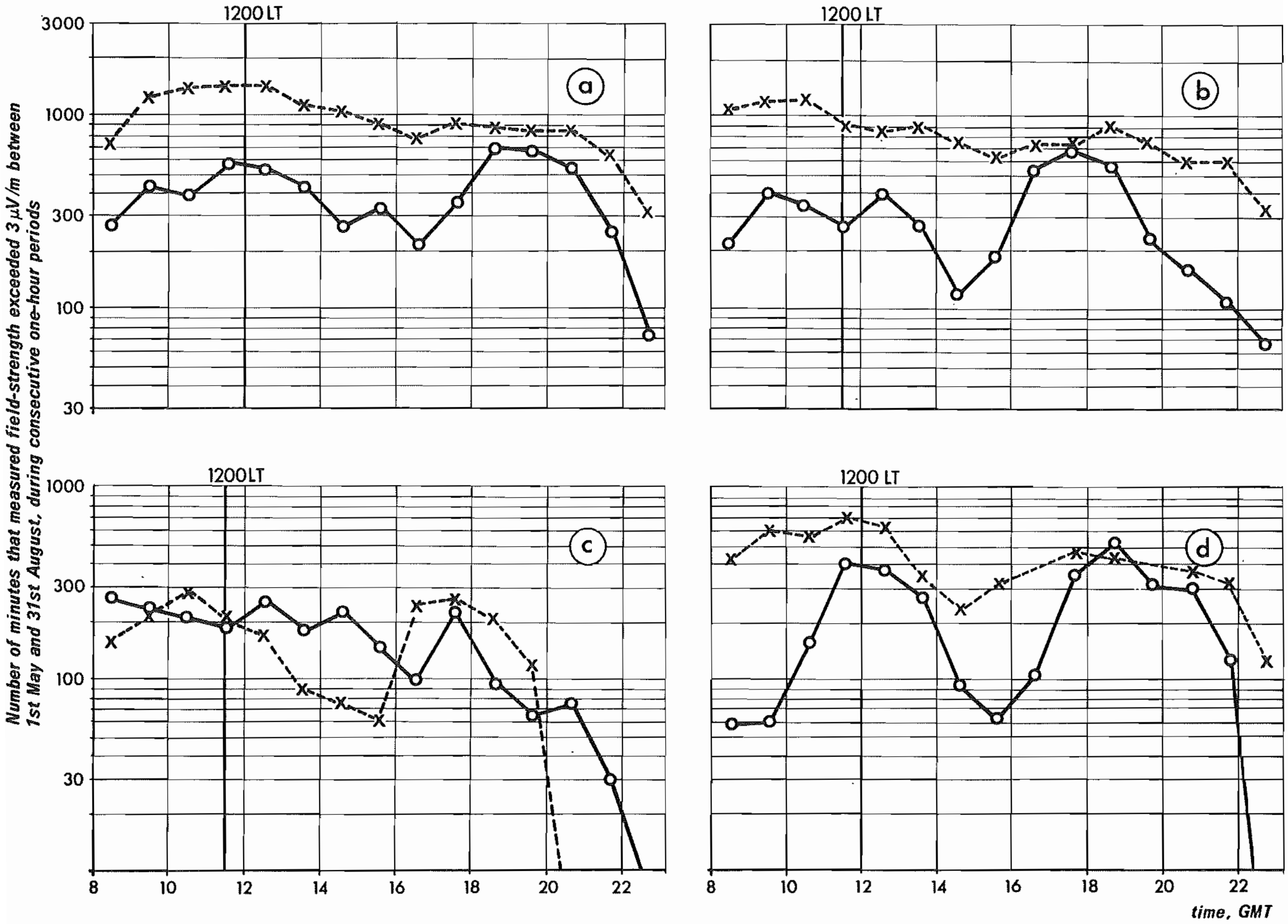

Fig. 7. - Diurnal variation.

a) Limoges - Orkney, 41.28 MHz
b) Divis - Helsinki, 41.465 MHz
c) Monte Sambuco - Stagshaw, 49.3 MHz
d) Carcassonne - Orkney, 54.43 MHz

—o— *1968*
--x-- *1969*

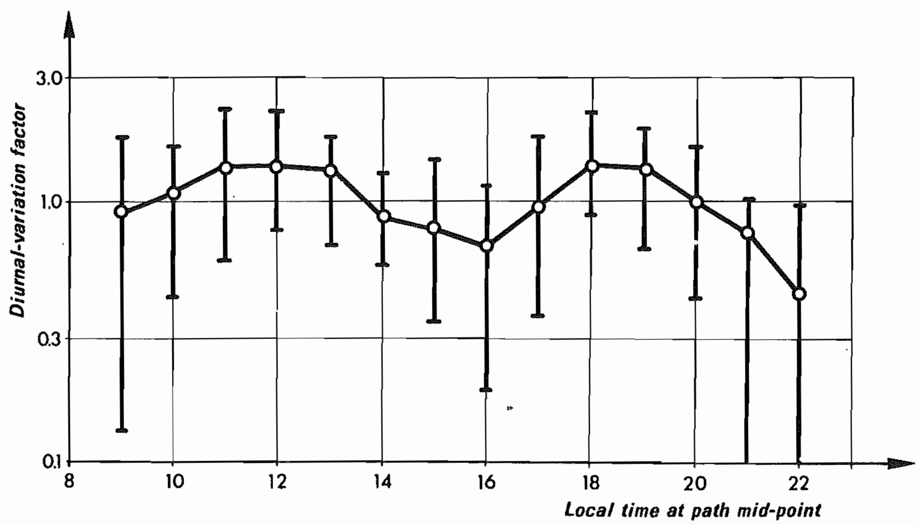

Fig. 8. - Diurnal-variation factor.

In *Fig. 8*, circles indicate median values for the 24 sets of data and vertical lines indicate the range of values encountered. The line joining the median values may be regarded as a diurnal-variation factor which may be applied to whole-day time percentages. For example, if a certain field-strength is exceeded for 5 % of the whole day (0800 to 2300 GMT), then *Fig. 8* shows that it is likely to be exceeded for $1.36 \times 5 = 6.8$ % of the time between 1730 and 1830, local time, during the summer months. The diurnal variation in the strength of sporadic-E signals (as opposed to the diurnal variation in their frequency of occurrence) cannot be derived from the analysis described in this section because it was confined to one particular field-strength level. A good indication of the diurnal variation of field-strength can, however, be derived from measurements, made in 1970 at Breisach, Federal Republic of Germany, of the transmissions from Divis, Monte Sambuco and Meldrum [8]. These measurements were analysed at three field-strength levels and show diurnal trends which are similar to those described in this section.

4. Duration of events

The subjective effect of interference caused by sporadic-E propagation may depend on the duration of individual periods of interference or "events". For example, viewers may not object to severe interference lasting for a few seconds but might be unwilling to tolerate weaker interference lasting for much longer periods.

Although a study of the subjective effect of sporadic-E interference is beyond the scope of the investigation described here, a limited study of the actual duration of events was carried out. For this study, the duration of an event was defined as the number of minutes that the field-strength continuously exceeded a certain reference level. The durations of all the events occurring on three paths during June 1971 were extracted from the recorder charts, the reference level being the field-strength normally exceeded for about 1 % of the total time during June. Details of the paths, number of events and their total duration are given in *Table 4*.

Table 4 - Duration of events

Path	Frequency (MHz)	Number of events	Total duration of events (min)	Total recording time (min)
Divis - Morlupo	41.465	204	710	10 800
Divis - Monte Lauro	41.465	427	1974	25 200
Meldrum - Morlupo	58.215	188	1020	12 600

The results of the analysis are contained in *Fig. 9*, which shows the percentage of events whose duration was less than a stated time. *Fig. 9* shows, for example, that over 70 % of events had durations of less than 2 minutes. The analysis also showed that occasional events of long duration accounted for the greater part of the time that interference was observed, only one quarter of the total time being contributed by events lasting less than 3 minutes.

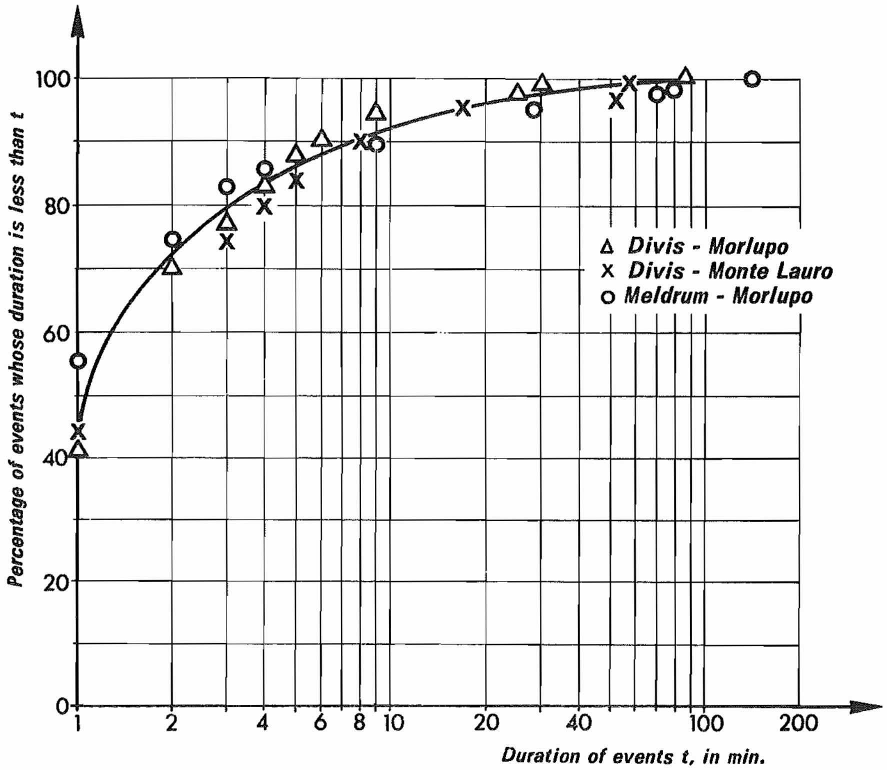

Fig. 9. - Duration of periods of interference or "events".

By "event" is meant the appearance of a field-strength that is continually higher than a certain reference level.

These results, which are still too limited, cannot be considered to be wholly reliable until supplementary studies have been undertaken. However, it may be both necessary and possible to undertake further research without waiting for the supplementary studies, in order to ascertain the subjective effect of this type of interference, and in particular, to determine whether, for a given total duration of interference, more disturbance is experienced by viewers when the interference takes the form either of a large number of short events, or a small number of long periods of interference, and thus whether different protection ratios should be adopted for the two types of interference.

5. Polarisation

The measurements provide no direct evidence of any relationship between the intensity of sporadic-E interference and the polarisation of the transmitted wave. Two transmissions of similar frequency but opposite polarisation would have to be measured simultaneously over the same path to provide such evidence. Theoretical considerations suggest, however, that the reflection coefficient of the ionosphere is probably independent of polarisation at VHF.

With tropospheric propagation, a worthwhile reduction of interference may often be achieved if pairs of co-channel transmitters radiate with opposite polarisations. To determine whether any corresponding advantage may be achieved when the interfering signal propagates via the ionosphere, simultaneous recordings were made on several paths with both vertical and horizontal aerials. Thus one aerial responded to the transmitted polarisation and the other aerial to the opposite polarisation. When sporadic-E propagation occurred, signals were usually received on both aerials, but the ratio of the two signals was liable to vary continuously, indicating a tendency for the incident wave to be randomly polarised. When the normal analysis described in Chapter 3 was applied, the field-strength/percentage-time distribution curves for the two aerials were found to be similar in shape although differing in level by a few dB.

Details of the paths where measurements were made with two aerials are given in *Table 1*. The results are contained in the first part of Volume II, where the pairs of tables for vertical and horizontal receiving aerials enable field-strengths exceeded for given time percentages to be compared directly. The difference in dBs between the two field-strengths may be called the polarisation ratio, assumed to be positive if the greater field-strength is that measured by the aerial which responds to the transmitted polarisation.

Consideration was given to the possibility that the polarisation ratio might depend on the reflection coefficient of the ionosphere; for example, the transmitted polarisation might be better preserved when the received signal is strongest. No evidence of any significant correlation between polarisation ratio and measured field-strength could, however, be detected. Consequently, the individual polarisation ratios for various months and time percentages were averaged for each path, giving the results for consecutive years contained in the penultimate column of *Table 5*. Calculation showed that the ratios for individual years did not differ significantly in the statistical sense. They were therefore averaged to give the single values for each path contained in the final column of *Table 5*.

The measurements show that the component of the downcoming wave which has the same polarisation as the incident wave is always slightly stronger than the opposite component. It would therefore appear reasonable to assume a value of 5 dB for polarisation discrimination for planning purposes when the interfering signal propagates via the sporadic-E layer.

Table 5

Polarisation ratio (transmitted polarisation/orthogonal polarisation)

Transmitter, frequency and polarisation	Receiver	Radiation angle (degrees)	Year	Polarisation ratio (dB)	Average polarisation ratio (dB)
Limoges 41.28 MHz H	Orkney	4.7	1970 1971	6.7 8.6	7.4
Monte Sambuco 49.30 MHz H	Kingswood	4.0	1966 1967	5.8 3.5	5.0
Carcassonne 54.43 MHz V	Kingswood	11.0	1966 1967	2.2 3.6	3.0
	Orkney	3.0	1970	4.6	4.6

6. Variation of field-strength with distance and frequency

Propagation curves showing how field-strengths vary with distance and frequency are useful for planning purposes. Since sporadic-E propagation causes interference to broadcasting, curves drawn for the months when interference occurs most frequently are of greatest value. *Fig. 6* shows that the worst interference occurs in June and July, when the field-strengths exceeded for given time percentages are greatest.

It might be considered that interference to co-channel stations should not be tolerated for more than 5 % of the time in any month and that, ideally, it should not occur for more than 1 % of the time in any month. Propagation curves showing the field-strengths which are exceeded for 1 % and 5 % of the time during the "worst" months of June and July have therefore been derived from the detailed results contained in Volume II.

The field-strengths contained in Volume II are standardised to an e.r.p. of 1 kW in the horizontal plane. However, *Fig. 2* shows that the power radiated towards the ionosphere is sometimes considerably less than that radiated horizontally, because of the vertical directivity of the transmitting aerial. To enable field-strengths observed on different paths to be compared, it is essential to take account of any difference between the e.r.p. in the horizontal plane and at the angle of elevation at which the wave is radiated. This was achieved by adding the v.r.p. correction factors given in *Table 1* to the field-strengths contained in Volume II, thereby standardising the measured field-strengths to an e.r.p. of 1 kW in the actual direction of radiation towards the ionosphere.

No additional allowance was made for the effect of the ground below the transmitting aerials even though this modifies their v.r.ps. *Table 2* shows that all the aerials were mounted on tall masts situated on hills or mountains. When an aerial is raised to a considerable height above the surrounding terrain, ground reflection gives rise to a multi-lobed v.r.p. whose envelope is almost exactly the same as that of the aerial in free space, the angular separation between adjacent lobes being of the order of 1°. The principal effect of the ground, therefore, is to increase the mean power radiated towards the ionosphere by up to 3 dB; the non-uniform illumination of the ionosphere is thought to be of little consequence because of the averaging effect caused by the movement of ionospheric irregularities. Since the increase due to ground reflection applies equally to all high-power transmitting stations, it can be disregarded in the construction of propagation curves provided it is also disregarded when they are used.

No allowance was made for the v.r.ps of the receiving aerials because they were erected at the same height as typical outdoor domestic aerials. Thus the propagation curves give the field-strengths which would cause interference at typical domestic aerials; this is, of course, the information which is required for the planning of broadcasting services.

Field-strengths exceeded for 1 % and 5 % of the time* during June and July in the 8 years from 1965 to 1972 were extracted from the tables of Volume II; this procedure normally yields 16 field strength values for each path and time percentage. Maximum, minimum and median values for each group of 16 field-strengths were deter-

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* It should be remembered that the time percentage under consideration relates to the period 0800 to 2300 GMT during which measurements have been made.

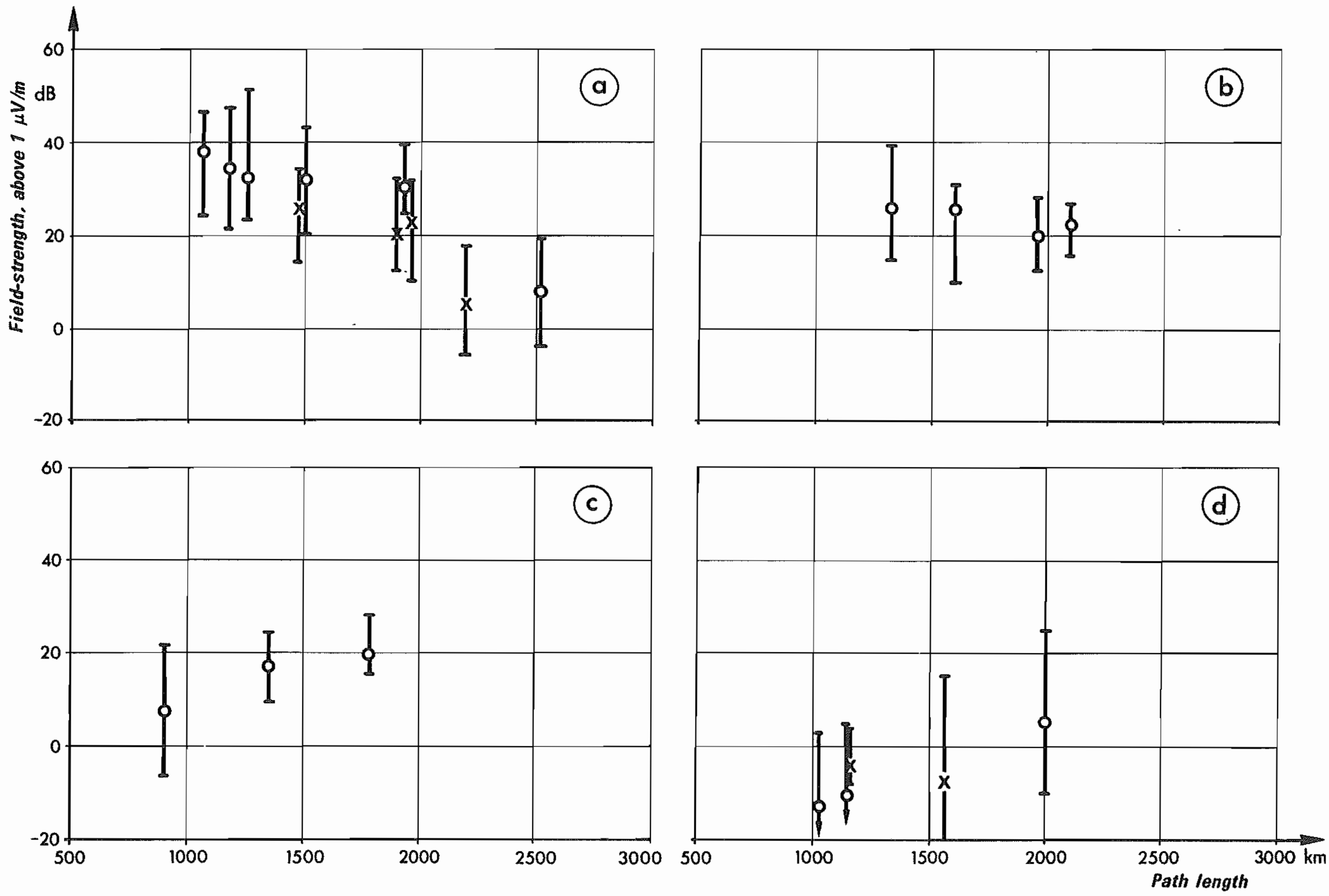

Fig. 10. - Field-strength exceeded for 1% of the time during June and July.

a) Limoges, 41.28 MHz and Divis, 41.465 MHz ***b) Monte Sambuco, 49.3 MHz***
c) Carcassonne, 54.43 MHz ***d) Meldrum, 58.215 MHz***
north-south paths ***north-European paths***

The ends of the arrows correspond to the noise level in the experiment under consideration.

mined and the v.r.p. correction factors given in *Table 1* were added. Measurements made before 1965 were excluded because recordings were made on only seven paths during the first three years of the measuring campaign.

Figs. 10 and *11* show the results of the analysis described in this section, plotted as a function of distance for individual frequencies. The points show the median value of each group of 16 field-strengths and the vertical lines indicate the range of values. Field-strengths less than -20 dB(μV/m) are not shown because this figure corresponded to receiver noise level on most paths.

A distinction has been made in *Figs. 10* and *11* between predominantly north-south paths and those which traverse Northern Europe. Although *Fig. 11* suggests that field-strengths exceeded for 5 % of the time on Northern European paths are significantly lower than elsewhere, *Fig. 10* shows that there is little difference between the field-strengths exceeded for 1 % of the time on the two types of path.

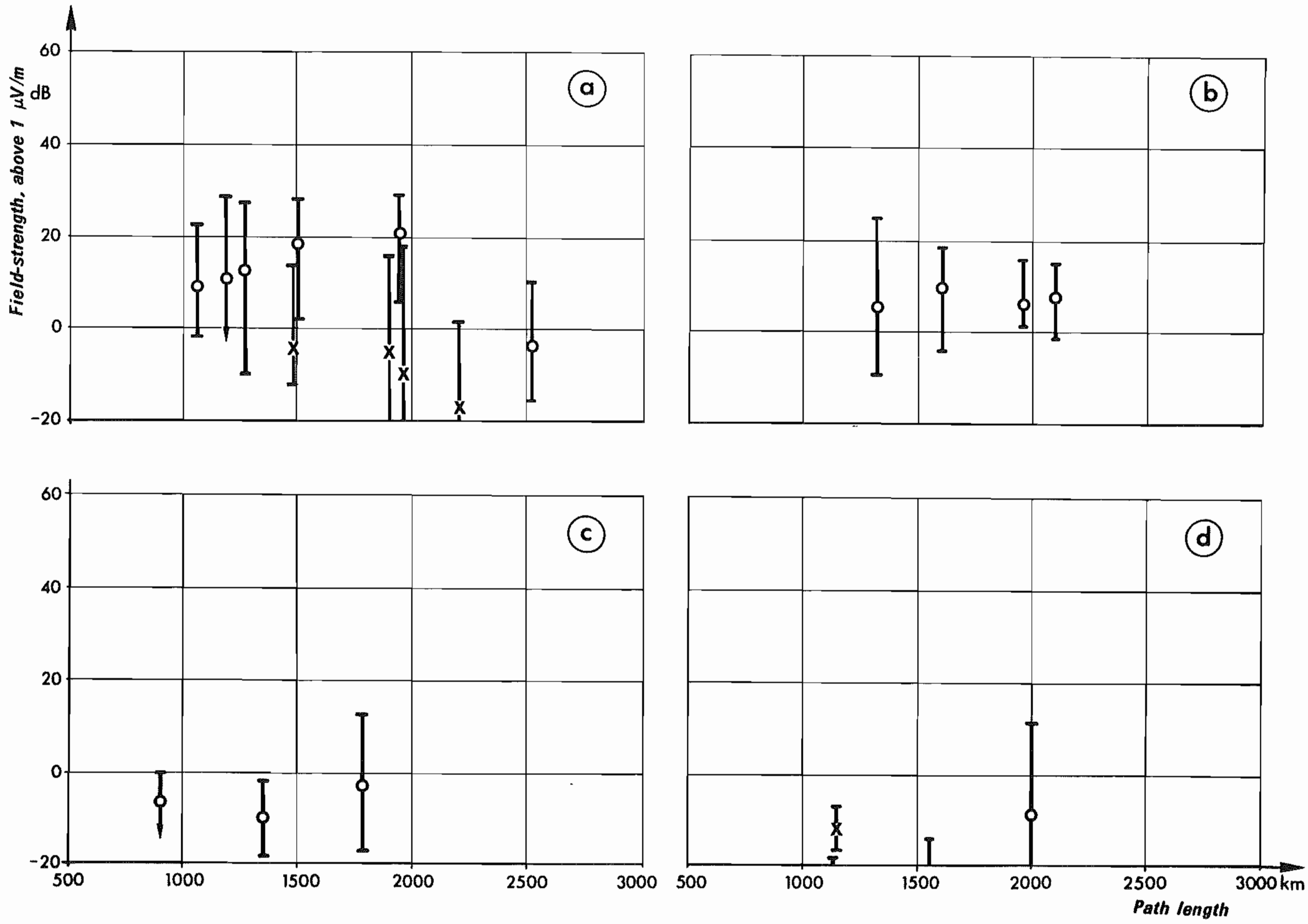

Fig. 11. - Field-strength exceeded for 5 % of the time during June and July.

a) Limoges, 41.28 MHz and Divis, 41.465 MHz
b) Monte Sambuco, 49.3 MHz
c) Carcassonne, 54.43 MHz
d) Meldrum, 58.215 MHz

north-south paths
north-European paths

The ends of the arrows correspond to the noise level in the experiment under consideration.

Despite the large number of paths over which measurements were made, insufficient data exists for complete propagation curves to be drawn, except at 41 MHz. There is, however, enough information for trends to be discerned and for tentative sets of propagation curves to be constructed. Sets of curves for field-strengths exceeded for 1 % and 5 % of the time have therefore been drawn; they are shown in *Fig. 12*, where they are compared with the median field-strengths for north-south paths taken from *Figs. 10* and *11*. As these curves are based on measurements made in June and July, correction factors given in Chapter 5 must be applied when they are used for other months. The somewhat lower field-strengths measured on Northern European paths were disregarded in drawing *Fig. 12b*, which should therefore be applied with caution to this area.

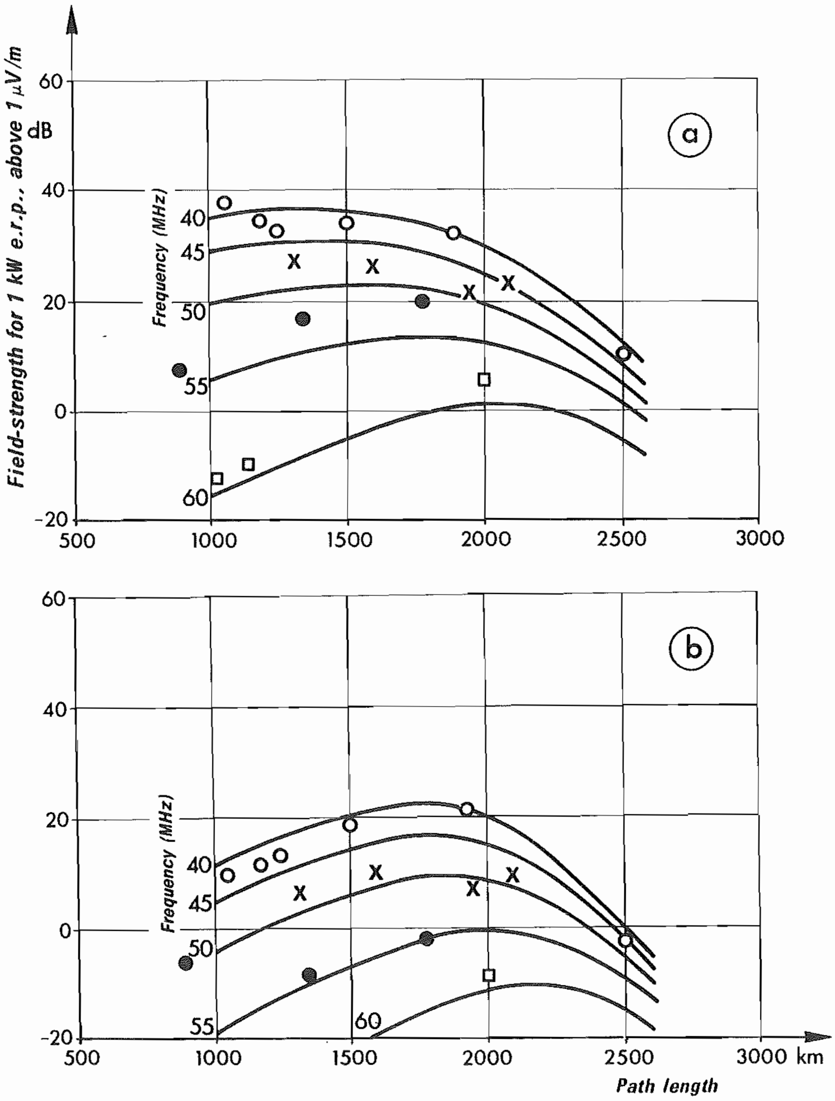

Fig. 12. - Propagation curves.

a) Field-strength exceeded for 1 % of the time
b) Field-strength exceeded for 5 % of the time

o *41.28 and 41.465 MHz* ● *54.43 MHz*
x *49.3 MHz* □ *58.215 MHz*

The points indicate the median field-strengths measured on north-south paths during June and July.

CHAPTER 5

A field-strength prediction method for VHF broadcasting in Europe

For planning, some method for predicting the strength and frequency of occurrence of interfering signals propagated via the sporadic-E layer is desirable. One possibility would be to use the method proposed by Miya and Sasaki [9] which has world-wide application. Miya and Sasaki's method depends on a knowledge of the critical frequency of the sporadic-E layer ($f_o E_s$) and the values it exceeds for different percentage times in various parts of the world. The field-strength exceeded for a specified percentage time on a given path is then calculated from the value exceeded by $f_o E_s$, with the help of charts. There are no restrictions on the types of transmitting and receiving aerials or on their height above ground.

While there is no reason why Miya and Sasaki's method should not be used for the planning of broadcasting services, a simpler and more convenient alternative, described in this section, is a prediction method based directly on measured field-strength rather than on the variation of $f_o E_s$. The method described here is also less complicated because it is restricted to the circumstances peculiar to broadcasting, where transmitting aerials are mounted on tall masts and receiving aerials are close to the ground. It applies only in Europe.

In the prediction method described here, the field-strength at a height of 10 m (typical of outdoor domestic receiving aerials) is given by

$$F(t) = E_o(t) + P - V - S \pm 10 \qquad (1)$$

where

$F(t)$ is the field-strength exceeded for t % of the time, dB above 1 μV/m;

t is the percentage of the total time between 0800 and 2300 hrs during all the days of one calendar month;

$E_o(t)$ is the basic field-strength, dB above 1 μV/m;

P is the e.r.p. in the horizontal plane in the direction of the great-circle path towards the receiver, dB above 1 kW.

V is the transmitting-aerial v.r.p. factor, dB

S is the seasonal correction, dB.

The basic field-strength $F_o(t)$ is given by the curves of *Fig. 12* for two values of *t*.

P, the e.r.p. in the horizontal plane, is usually specified for transmitting installations.

The transmitting aerial v.r.p. factor *V* is the reduction in e.r.p., due to vertical directivity, which applies at the angle of elevation for propagation to the receiver via the sporadic-E layer. This angle of elevation, known as the *radiation angle*, is given by *Fig. 13*.

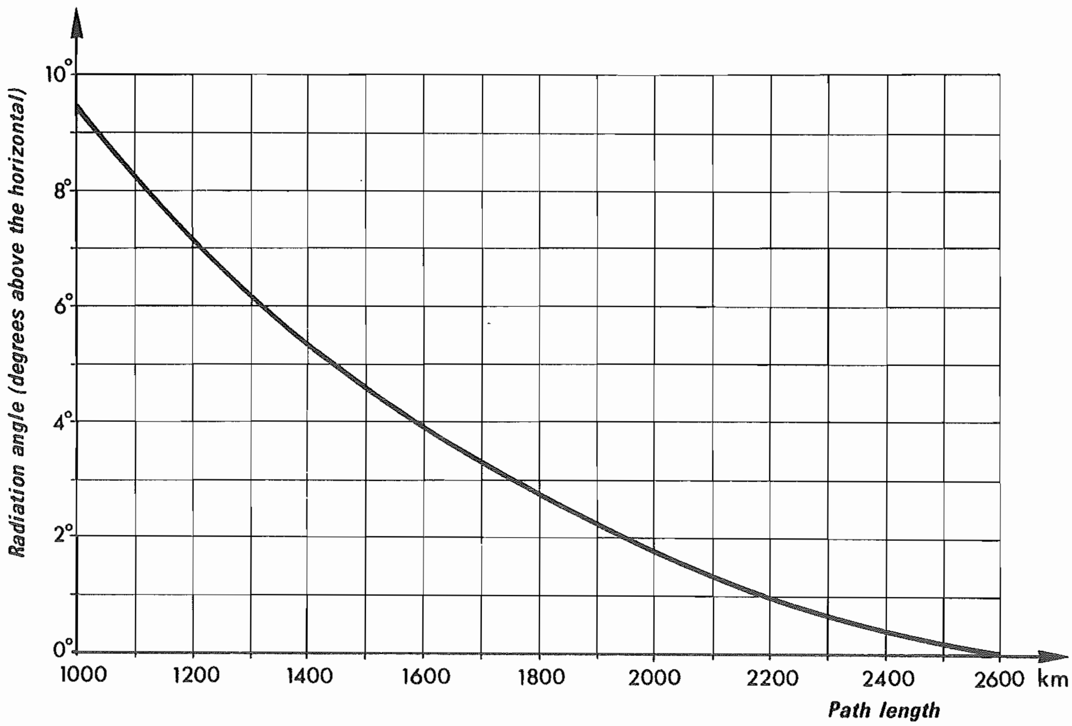

Fig. 13. - Median radiation angle for propagation via the sporadic-E layer.

Table 6 - Seasonal corrections

Month	S (dB)
April	30
May	10
June	-1
July	1
August	5
September	22
October	21

Table 6, which is based on *Fig. 6*, gives seasonal corrections *S* for the summer months.

The final term in equation (1), i.e. ± 10 dB, is required because the field-strength observed in any given month may differ from the predicted value by up to 10 dB. This degree of uncertainty is indicated by the error bars of *Figs. 6, 10* and *11*. Field-strengths exceeded for 5 % of the time on Northern European paths may be a further 20 dB lower.

The prediction method makes no allowance for diurnal variation because the amount by which the field-strength differs from the predicted value at specific hours of the day has not yet been determined. The percentage time that the predicted field-strength will be exceeded during any specified hour can, however, be estimated by multiplying *t* by the diurnal-variation factor given in *Fig. 8*.

An example of the use of the prediction method is contained in the *Appendix*.

CHAPTER 6

Conclusions

The main conclusions from the investigation may be summarised as follows:

1. Solar activity has very little effect on sporadic-E propagation. Although there is a slight tendency for field-strengths to be lower at the peak of the solar cycle, there is no need to take this factor into account when planning broadcasting services.

2. Sporadic-E propagation occurs during spring, summer and autumn. It causes most interference during June and July, and slightly less interference during May and August. There is considerably less interference during April and September but there is a tendency for sporadic-E propagation to occur slightly more frequently in October than in September. Sporadic-E propagation is seldom observed after October or before April.

3. Sporadic-E propagation occurs mainly during the day and early evening, with peak activity at noon and at 1800 hrs, and a slight minimum at 1600 hrs. These times are local times at the path mid-point.

4. When sporadic-E propagation occurs it usually lasts for less than three minutes. Occasional events of much longer duration, however, account for the greater part of the total time during which it is observed.

5. The polarisation of the transmitted wave is modified by the ionosphere. Measurements with vertical and horizontal receiving aerials have shown that the component of the received signal whose polarisation is the same as that of the transmitted wave is on average about 5 dB stronger than the orthogonal component.

6. Waves propagated via the sporadic-E layer cause interference at distances between about 800 and 2600 km. VHF transmissions seldom propagate to shorter distances because they penetrate the ionosphere, or to greater distances because these are beyond the range of 1-hop propagation via the E layer. If the vertical directivity of a transmitting aerial is increased, less interference should be experienced at the shorter distances for a given e.r.p. in the horizontal plane but this has not been confirmed experimentally.

7. The field-strength decreases rapidly as the frequency increases, especially at the shorter distances, because of E-layer penetration. For planning purposes, interference caused by sporadic-E propagation can be neglected at frequencies above 60 MHz.

8. Field-strengths exceeded for 5 % of the time on Northern European paths are about 20 dB lower than values observed on more southerly paths. There is, however, very little difference between the field-strengths exceeded for 1 % of the time.

9. The occurrence of sporadic-E propagation varies from day to day in a completely random manner. Its occurrence from one year to another is also somewhat random and consequently it is impossible to predict the field-strength which will be exceeded for a specified percentage of the whole of a given month with an accuracy better than ± 10 dB.

Since the measurements were confined to Western and Northern Europe, the conclusions summarised above should not be applied to other areas even though they may lie within the temperate zone. Use of the field-strength prediction method described in Chapter 5 should also be confined to Western and Northern Europe.

APPENDIX

An example of the use of the field-strength prediction method

Estimate the field-strength exceeded for 1 % of the time between 0800 and 2300 hrs during August on a 1500 km path, when a transmitter radiates on a frequency of 45 MHz with an e.r.p. of 5 kW, from an aerial whose v.r.p., at low angles of elevation (Δ), is given approximately by cos 10Δ. Then estimate the percentage of time that this field-strength is exceeded between 1830 and 2230 hrs. All times are local times at the path mid-point.

From *Fig. 12a*, the basic field-strength $E_o(t)$ is 30 dB(μV/m).

For an e.r.p. of 5 kW, P is equal to 7 dB.

Fig. 13 shows that $\Delta = 4.6°$ for a 1500 km path. Since cos $10\Delta = 0.695$, the transmitting-aerial v.r.p. factor V is 3 dB.

The seasonal correction for August, S, given by *Table 6*, is 5 dB.

From equation (1), the estimated field-strength is therefore

$$F(t) = 30 + 7 - 3 - 5 \pm 10 = 29 \pm 10 \text{ dB}(\mu\text{V/m})$$

The diurnal-variation factors for the four hours between 1830 and 2230 hrs, given by *Fig. 8*, are 1.32, 1.00, 0.76 and 0.44. These figures may be averaged to give a mean factor for the four-hour period of 0.86. It follows that the estimated field-strength will be exceeded for $0.86 \times 1 = 0.86$ % of the time during this period.

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Acknowledgments

A great deal of effort was involved in making the measurements and in their subsequent analysis. It is impossible to acknowledge the contributions made by all the people concerned individually, but an attempt has been made here to record the names of the organisations which participated in the campaign.

The RAI (Italy) installed and operated a special transmitter at Monte Sambuco. The other transmissions were provided by the O.R.T.F. (France) and the B.B.C. (United Kingdom); although these were normal service transmissions they were sometimes radiated outside regular programme hours.

The receiving equipment was constructed and operated by the RAI, O.R.T.F., B.B.C., YLE (Finland), by the Postal Authorities of Sweden, Federal Republic of Germany and Switzerland, and by the E.B.U. A set of receiving equipment was also operated by the Electrical Engineering Department of Edinburgh University.

The organisations responsible for the receiving equipment in Sweden, Italy, Finland, Switzerland and Federal Republic of Germany also analysed the recordings they produced. All other recordings were analysed by the B.B.C. and the standardisation of all the measurements was undertaken by the B.B.C.

The B.B.C. was also mainly responsible for the final analysis of the results, described in Chapter 4 of this document. The analysis described in Section 4 of this chapter, however, was performed by the RAI and that described in Section 3 originated at the O.R.T.F.

Thanks are due to all the organisations mentioned above for the contributions they made to the successful outcome of the measuring campaign.

Price : 80 Belgian francs