RECOMMENDATION 534-3

METHOD FOR CALCULATING SPORADIC-E FIELD STRENGTH

(Question 41/6)

(1978-1982-1986-1990)

The CCIR,

CONSIDERING

(a) that propagation by sporadic E is an important source of interference at low VHF;

(b) that the calculation method of sporadic-E field strength given in Annex I to this Recommendation has been proved to be practical and reliable;

(c) that there exists no other practical method,

UNANIMOUSLY RECOMMENDS

1. that the calculation method in Annex I be adopted as the method to be used for estimation of sporadic-E field strength for the low- and mid-dip latitudes;

2. that more foEs and sporadic-E field strength data be collected, particularly in the high latitude regions. In the meantime, caution should be exercised if the method in Annex I is used in these regions.

ANNEX I

METHOD FOR CALCULATING SPORADIC-E FIELD STRENGTH

1. Introduction

The present text sets out a statistical method for calculating the field strength of signals propagated by means of ionospheric sporadic E (Es) at VHF and, possibly, at higher portions of the HF bands, for distances up to 4000 km. The calculation is based upon the fact that the field strength is very closely correlated with foEs, that is to say, the critical frequency of sporadic-E layer at vertical incidence at the path mid-point. It should be noted that the method is suitable for application to an ionospheric radio circuit in the case where the regular propagation mode via the E or F2 layer does not exist. When using the method at HF therefore, caution should be exercised if the possibility of regular layer propagation exists. (See Recommendation 533 for regular-layer propagation.) The method, which is essentially the same as the method described by Miya and Sasaki [1966], Miya *et al.*, [1978], has been refined taking particular account of data obtained from the EBU ten year measurement campaign [EBU, 1976] for the modification of the original ionospheric attenuation chart and also with the provision of some charts of foEs submitted by members of Interim Working Party 6/8. Since the data provided by the Recommendation refer to geomagnetic latitudes between $\pm 60°$, it is necessary to continue to examine the applicability of the method, especially in the high latitude regions.

Experimental results which show good agreement with this prediction method have been provided by a USSR experiment on 9, 14, 24 and 44 MHz over a 1050 km path [CCIR, 1978-82] and also by the Argentine Republic on 47.620 MHz over a 1070 km path [Giraldez, 1984], both being in mid-magnetic latitude regions.

In the equatorial region some experimental results of medium distance propagation (500-2000 km), clearly indicate Es propagation, which must be distinguished from the much more important effects of trans-equatorial propagation (TEP) in the area (see Report 259). Low latitude Es propagation field strength is approximately the same as estimates for mid-latitudes in this Annex. However the parameter showing the greatest change is the percentage of time as a function of the vertical incidence critical frequency (foEs) (Figs. 2 to 6 for middle magnetic latitudes). Therefore, alternative Figs. 16 to 21 are provided for use in the low magnetic latitude region.

The method has the following features:

– Es field strength is predicted by means of the statistical correspondence of a value of ionospheric attenuation to that of foEs at a given rate of occurrence;

– the ionospheric attenuation of the Es signal is represented by a function of the ratio of the signal frequency f to foEs and the surface distance between the transmitting and receiving stations;

– some useful probability charts and world maps of foEs are provided for quick and easy evaluation of the Es field strength.

2. Formula for sporadic-E field strength

Es signal strength can be expressed as follows:

$$E = E_0 + P + G_t - L_t - \Gamma \qquad \text{dB} \tag{1}$$

$$E_0 = 105 - 20 \log l \qquad \text{dB} \tag{2}$$

where

E : predicted field strength (dB(μV/m));

E_0 : theoretical inverse distance field strength (dB(μV/m)), for 1 kW radiated power and isotropic transmitting antenna;

P : transmitter power (dB(1 kW));

G_t : gain of the transmitting antenna relative to an isotropic antenna, (dB);

L_t : loss of the transmitting antenna, (dB);

Γ : ionospheric attenuation (dB) as shown by the solid line curves in Fig. 1;

l : transmission path length (km), (see equation (5)).

For the calculation by computer, Γ for single-hop propagation signal, $\Gamma_{(1\text{ - hop})}(d)$, is given approximately by:

$$\Gamma_{(1\text{ hop})}(d) = \left\{ \frac{40}{1 + \left(\frac{d}{130}\right) + \left(\frac{d}{250}\right)^2} + 0{,}2 \left(\frac{d}{2\,600}\right)^2 \right\} \left(\frac{f}{\text{foEs}}\right)^2 + \exp\left(\frac{d - 1\,660}{280}\right) \tag{3}$$

and Γ for double-hop propagation signal, $\Gamma_{(2\text{ – hop})}(d)$ approximately by:

$$\Gamma_{(2\text{ hop})}(d) = 2.6\,\Gamma_{(1\text{ hop})}\left(\frac{d}{2}\right) \tag{4}$$

and

l : transmission path length (km) is given by:

$$l = (d^2 + 4\,h^2)^{1/2} \tag{5}$$

where

h : height of Es layer; (km);

d : surface distance between the transmitting and receiving stations (km);

f : signal frequency (MHz);

foEs : critical frequency of sporadic-E at vertical incidence at a given rate of occurrence (MHz);

The accuracy with which equations (3) and (4) reproduce the measured values of Γ is indicated in Fig. 1 where they are plotted as the broken line curves. The use of equation (3) should be restricted to distances less than 2600 km with the values of f/foEs between 1 and 8, where the error is less than 5 dB. The use of equation (4) should be restricted to distances between 2600 and 4000 km, and to values of f/foEs between 2 and 5.5; the error will then be less than 10 dB.

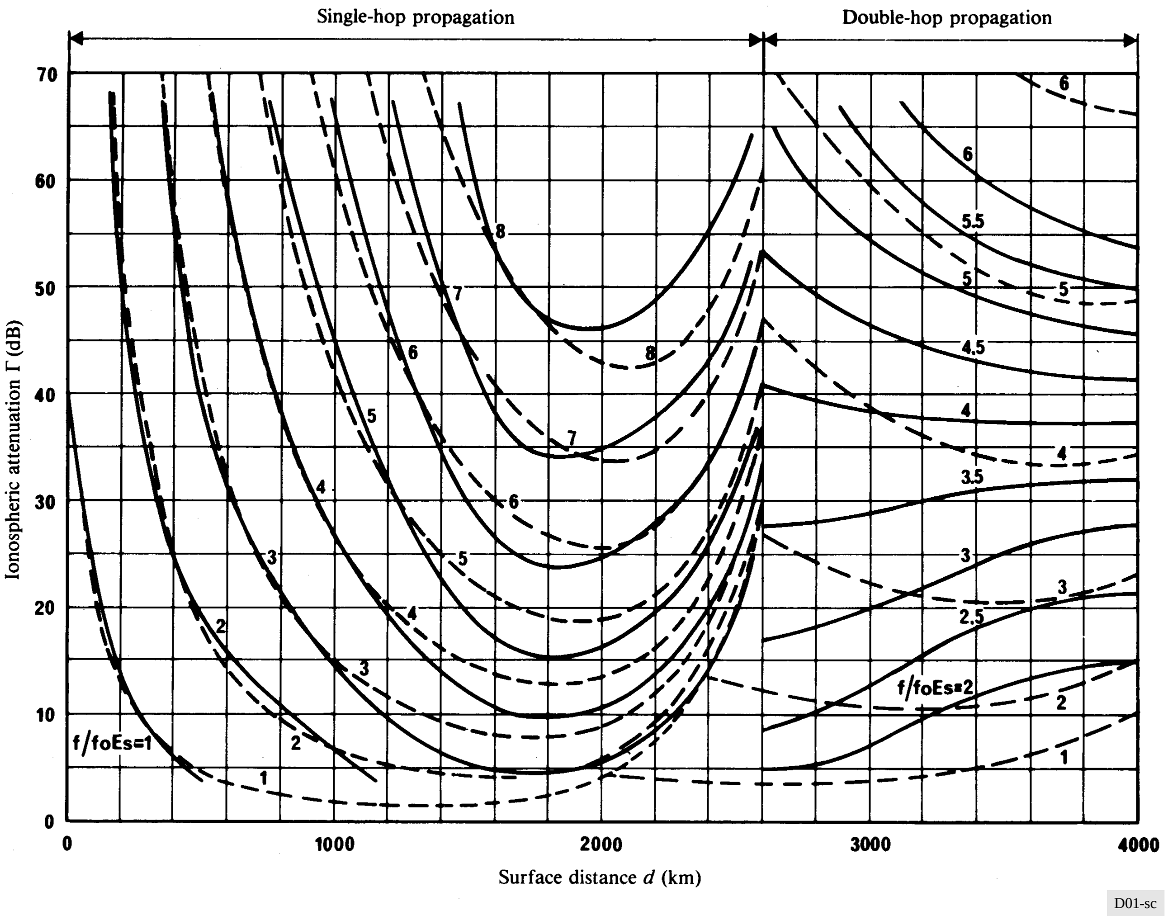

FIGURE 1 – *Chart of ionospheric attenuation* Γ *for Es propagation*

——— from observed values
– – – from empirical formulae (3) and (4)

3. A procedure for calculating sporadic-E field strength

A procedure for calculating Es field strength is as follows:

– first step: calculate a value of E_0 corresponding to given value of l using equation (2);

– second step (path mid-point dip latitude outside ±20°): read off a value of foEs at a given time percentage of occurrence in the desired region and season using one of Figs. 2 to 6. If a more accurate prediction is required, read off a value of the percentage of time that foEs exceeds 7 MHz at the path mid-point using a pertinent map of Figs. 12 to 15 and determine a value of foEs by drawing a new line on the relevant one of Figs. 2 to 6 as described in § 4.1. If a prediction of diurnal variation is required, read off a value of foEs on a pertinent figure of Figs. 7 to 11;

– second step (path mid-point dip latitude within ±20°): determine the dip angle for the ionospheric reflection point and read off a value of foEs at a given percentage of time of occurrence under the desired region and season using Figs. 16 to 21;

– third step: calculate *f*/foEs;

– fourth step: using the solid line curves in Fig. 1, read off a value of Γ corresponding to the given value of *d* and the calculated *f*/foEs, or, for an approximate value, calculate Γ using equations (3) and (4);

– fifth step: calculate the predicted value of E by equation (1), using given values of P, G_t, L_t and the value obtained for Γ.

4. Probability of occurrence of foEs

It is necessary to clarify the statistical characteristics of foEs since it undergoes sporadic behaviour changes with location and time. The world map of foEs, such as that of Part 6 of Report 340, can be used for high accuracy of prediction. On the other hand, simplified statistical data of foEs are also very useful in cases where the general tendency of temporal variation is to be obtained.

For the purpose of predicting the average Es field strength, probability curves of foEs have been prepared for the five mid-latitude regions of Europe and North Africa, North America, Asia (Far East), South America and a buffer region between these regions as shown in Figs. 2 to 11. For low latitudes, probability curves of foEs have been prepared for America, Asia and Africa as shown in Figs. 16 to 21. The high latitude region characteristics need to be further clarified in the future.

4.1 *Mid-latitudes*

To provide detailed geographic characeristics of foEs, the world maps of the percentage of time for which foEs is equal to or greater than 7 MHz during the months of May-August (northern summer), November-February (southern summer), the months of March, April, September and October (equinoctial months, north and south) and for twelve months, are specifically included as Figs. 12-15 [Smith, 1976, 1978]. As may be seen in these world maps, contours of time percentage are shown between 60° geomagnetic (or dipole) north and south latitudes. A low latitude region around the dip equator is excluded.

Figures 2 to 6 show the relation between the value of foEs and the time percentage of its occurrence. In these figures, curves for the summer months, winter months and equinoctial months are all represented by straight lines connecting two points corresponding to values of time percentage exceeding 7 MHz and 10 MHz, respectively, of foEs. These are subject to the so-called Phillips' frequency-dependence rule. This rule is a strictly empirical one which works quite well at mid-latitudes for percentages of time less than about 30% and for frequencies above foE, the critical frequency of the normal E layer. Caution should be exercised in the use of the Phillips rule for frequencies above about 100 MHz and for equatorial and high latitudes. The Phillips rule is:

$$\log p = a + b f \tag{6}$$

where

p : probability of occurrence of foEs > f,

f : frequency (MHz),

a and b : are adjustable constants, such that b is the slope in a plot of log p as a function of f.

A curve showing the annual average, has values of time percentage of about one third of the corresponding values for the summer months in the low percentage of time ranges. For reference, probability curves are added to the respective figures for the period of daytime (0800-2300 h) in the summer months, when the most intense sporadic E is observed.

When there exists a difference between a value of time percentage of foEs for 7 MHz, as obtained by the world maps in Figs. 12, 13, 14 or 15 and that obtained by the average probability curve for a Region, as seen in Figs. 2 to 6, a value of foEs may be determined for a given percentage of time, by using a new probability curve redrawn so as to be parallel to the original curve in the respective region and displaced by an amount equal to the difference of those values.

Figures 7 to 11 exhibit diurnal variations of occurrence of foEs in a time block of 4 hours in the above four regions for the summer and non-summer months, according to their distinctive characteristics. It is noticeable that a definite minimum of foEs is observed shortly after midday in regions B and C, particularly in summer. For the purpose of predicting the detailed behaviour of Es signal strength, it may be necessary to show the diurnal variations of foEs in terms of a time block smaller than 4 hours.

4.2 *Low latitudes*

Figures 16 to 21 show the relation between the value of foEs and the time percentage of its occurrence for low latitudes. In these figures, a clear difference is observed between a very narrow belt around the dip equator (± 6° dip angle) and the adjacent region up to ± 20° dip, which might be called equatorial and sub-equatorial regions respectively. As seen from comparison with Figs. 2 to 6, the sub-equatorial region, but not the equatorial one, is subject to the Phillips law.

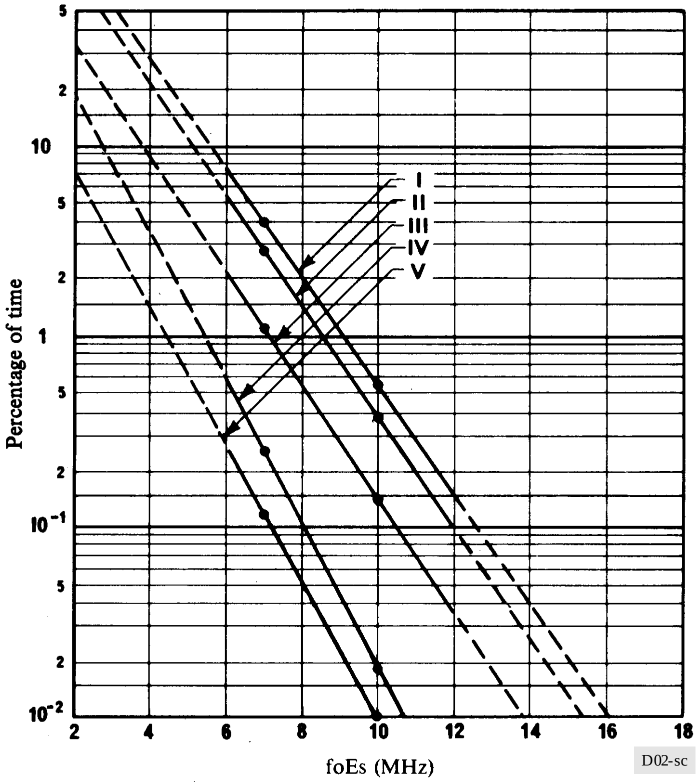

FIGURE 2 – *Values of foEs equalled or exceeded for indicated percentage of time for region A*

Region A: Europe and North Africa
I: May to August (0800-2300 h)
II: May to August
III: annual average
IV: March, April, September and October
V: November to February

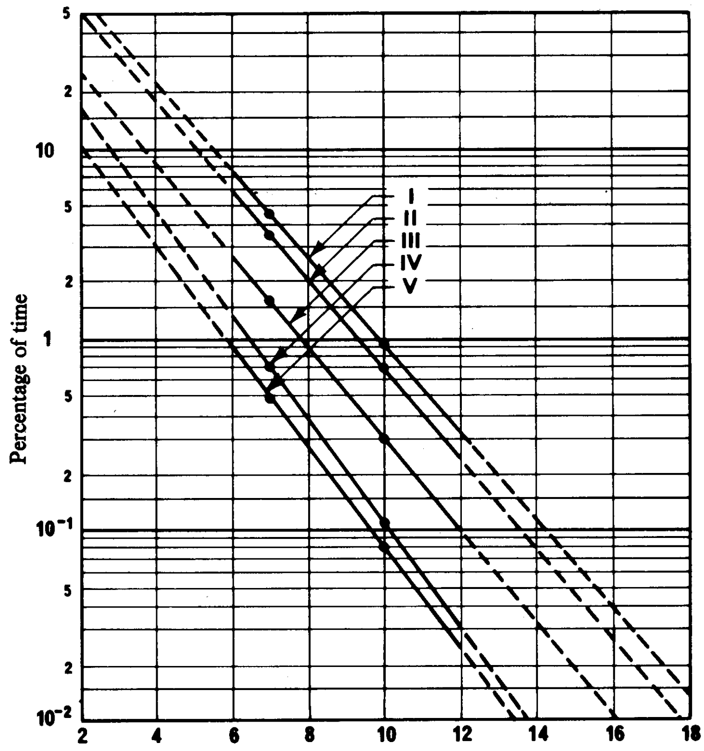

FIGURE 3 – *Values of foEs equalled or exceeded for indicated percentage of time for region B*

Region B: North America
I: May to August (0800-2300 h)
II: May to August
III: annual average
IV: March, April, September and October
V: November to February

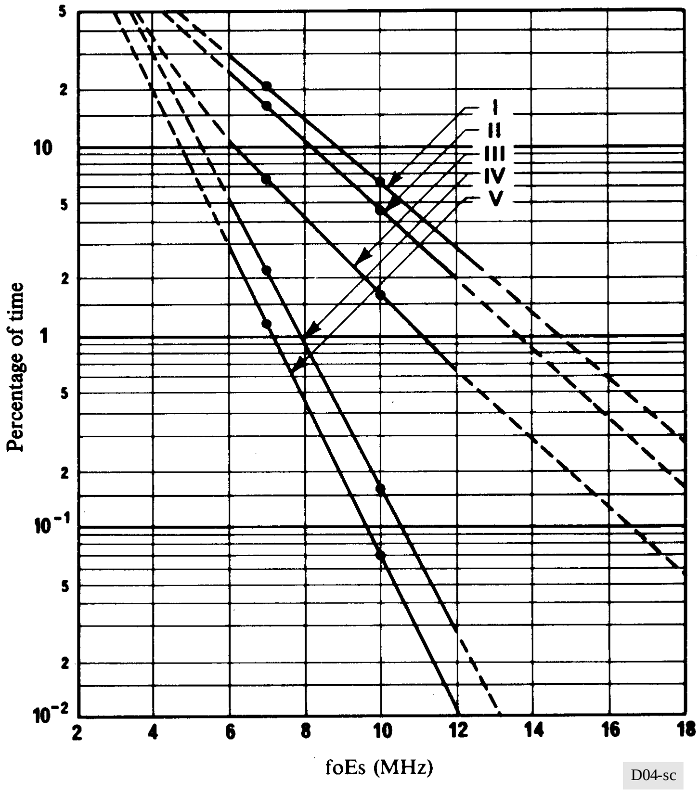

FIGURE 4 – *Values of foEs equalled or exceeded for indicated percentage of time for region C*

Region C: Asia (Far East)
I: May to August (0800-2300 h)
II: May to August
III: annual average
IV: March, April, September and October
V: November to February

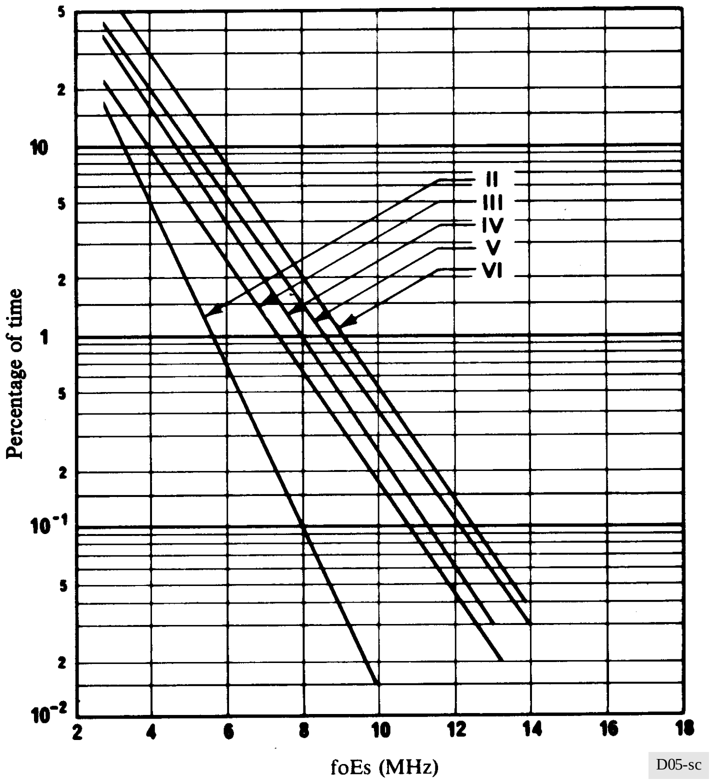

FIGURE 5 – *Values of foEs equalled or exceeded for indicated percentage of time for region D*

Region D: South America
II: May to August
III: annual average
IV: March, April, September and October
V: November to February
VI: November to February (0800-2300 h)

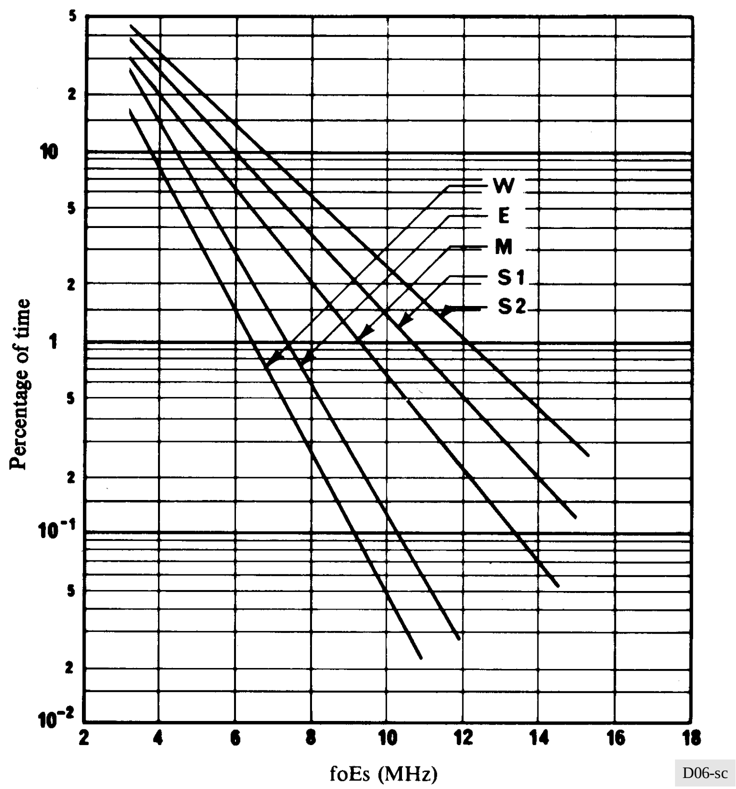

FIGURE 6 – *Values of foEs equalled or exceeded for indicated percentage of time*

Mean value: regions A, B, C and D
S1: summer
S2: summer (0800-2300 h)
M: annual average
E: equinox
W: winter

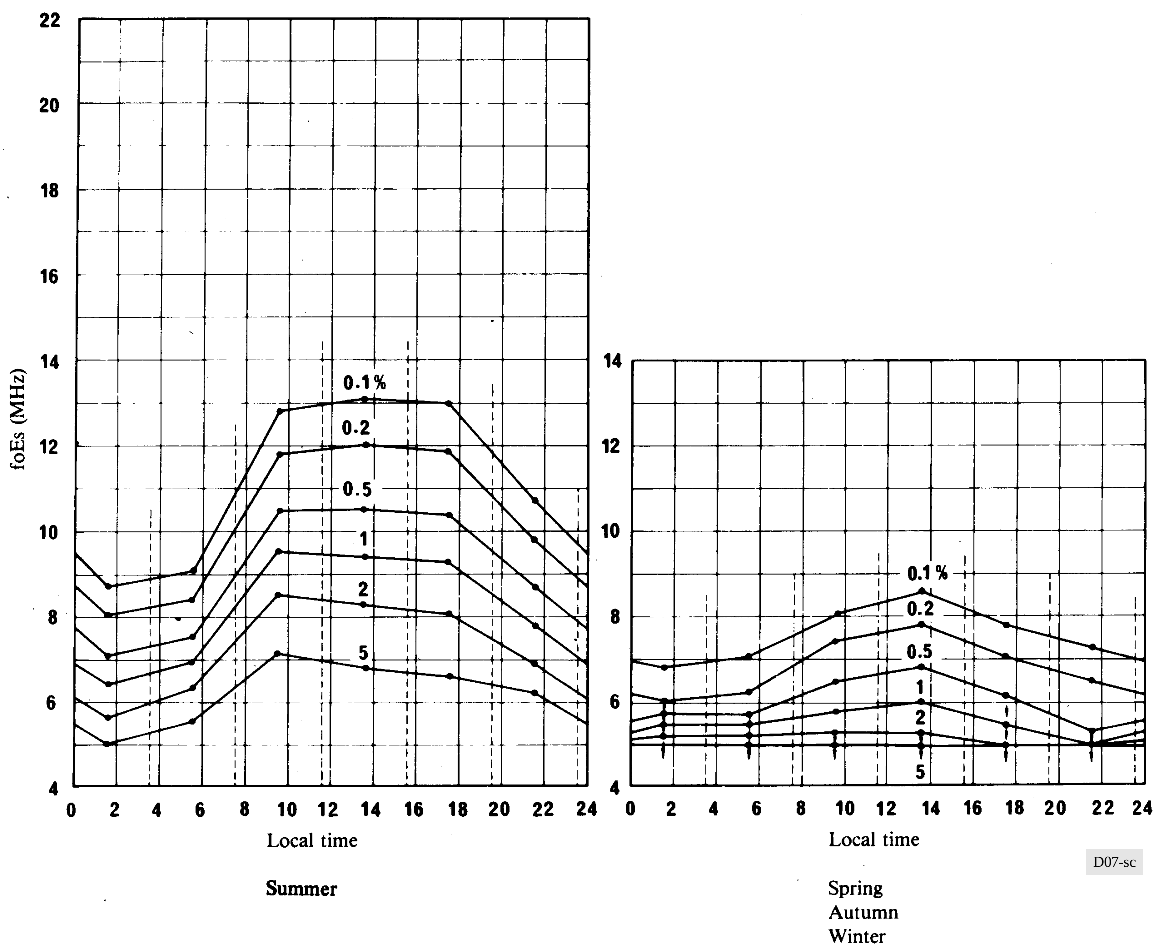

FIGURE 7 – *Values of foEs equalled or exceeded for the percentage of time indicated as the parameter on the curve during time blocks shown separated by the dotted vertical lines of 4 hours for region A (Europe and North Africa)*

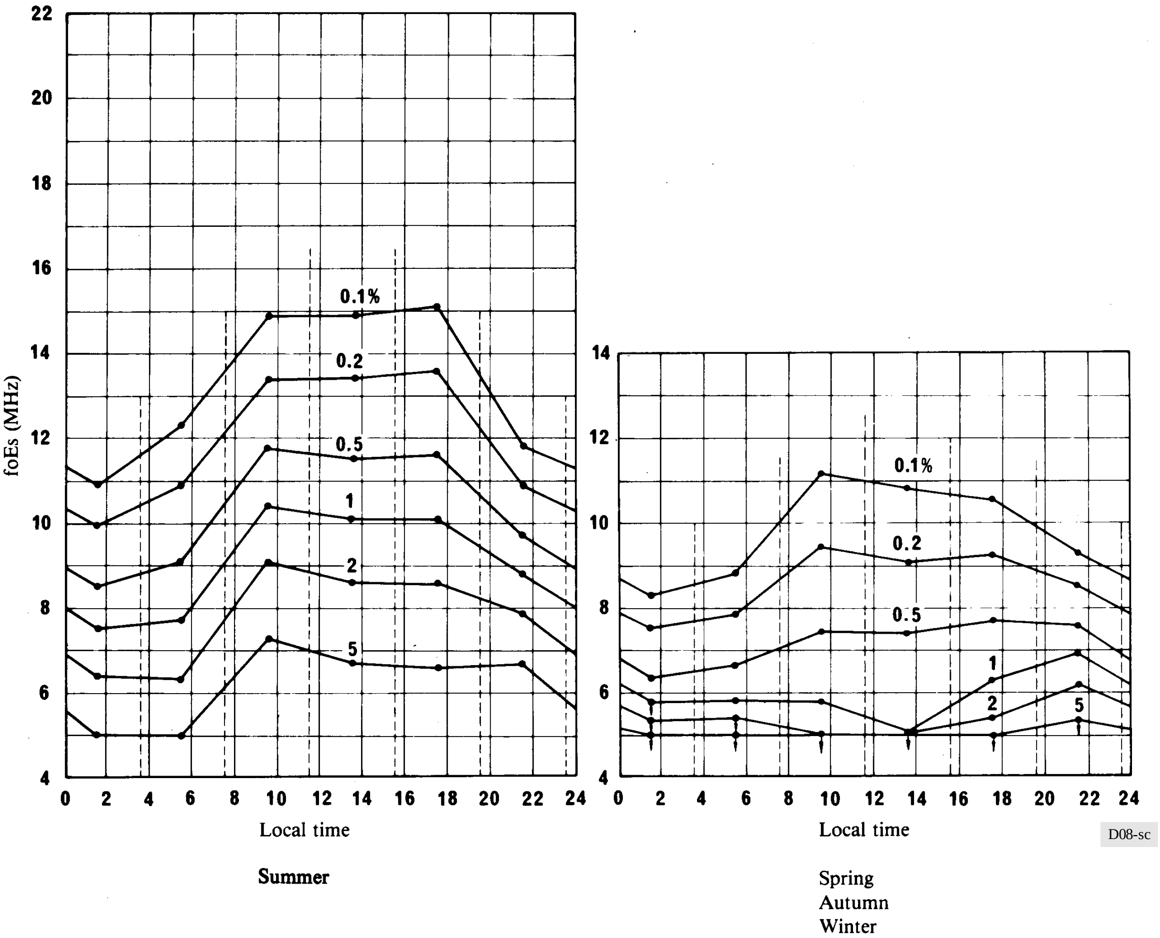

FIGURE 8 – *Values of foEs equalled or exceeded for the percentage of time indicated as the parameter on the curve during time blocks shown separated by the dotted vertical lines of 4 hours for region B (North America)*

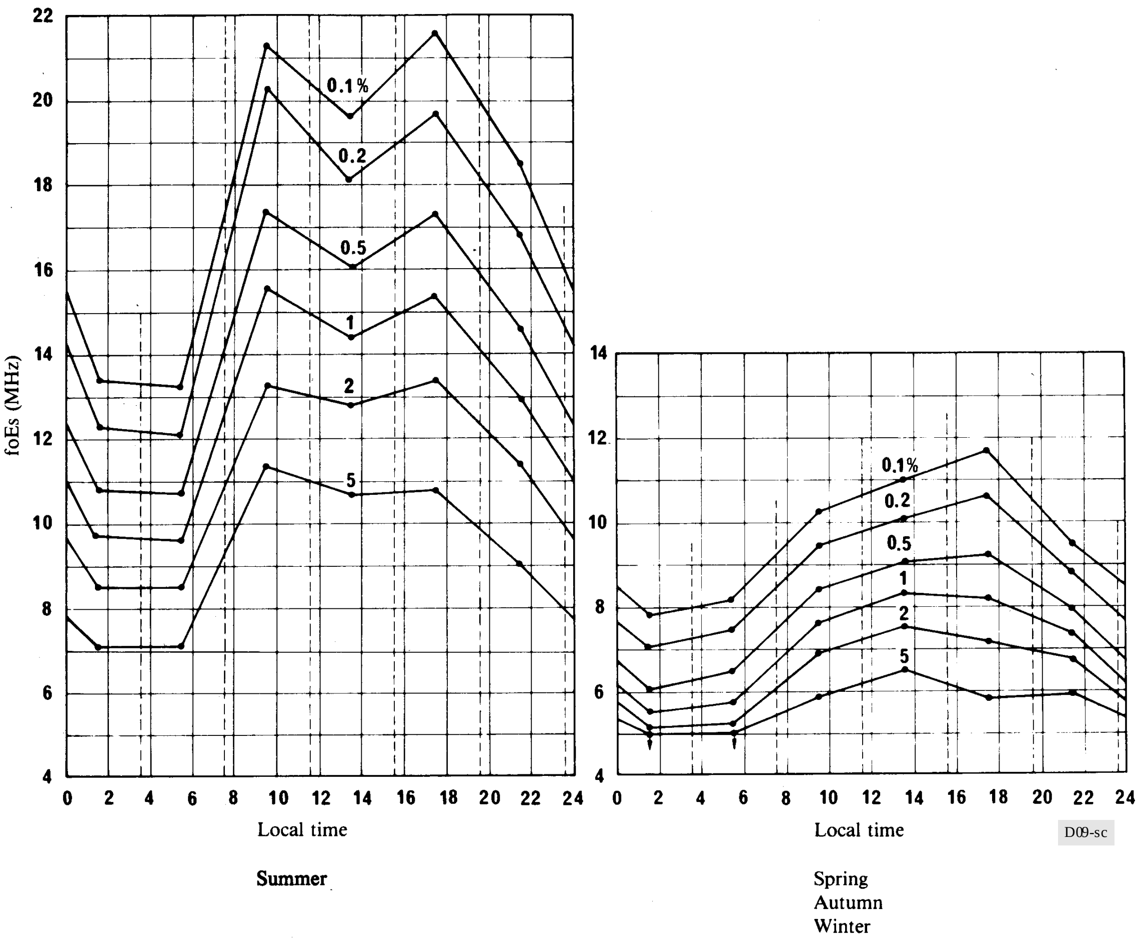

FIGURE 9 – *Values of foEs equalled or exceeded for the percentage of time indicated as the parameter on the curve during the time blocks shown separated by the dotted vertical lines of 4 hours for region C (Asia (Far East))*

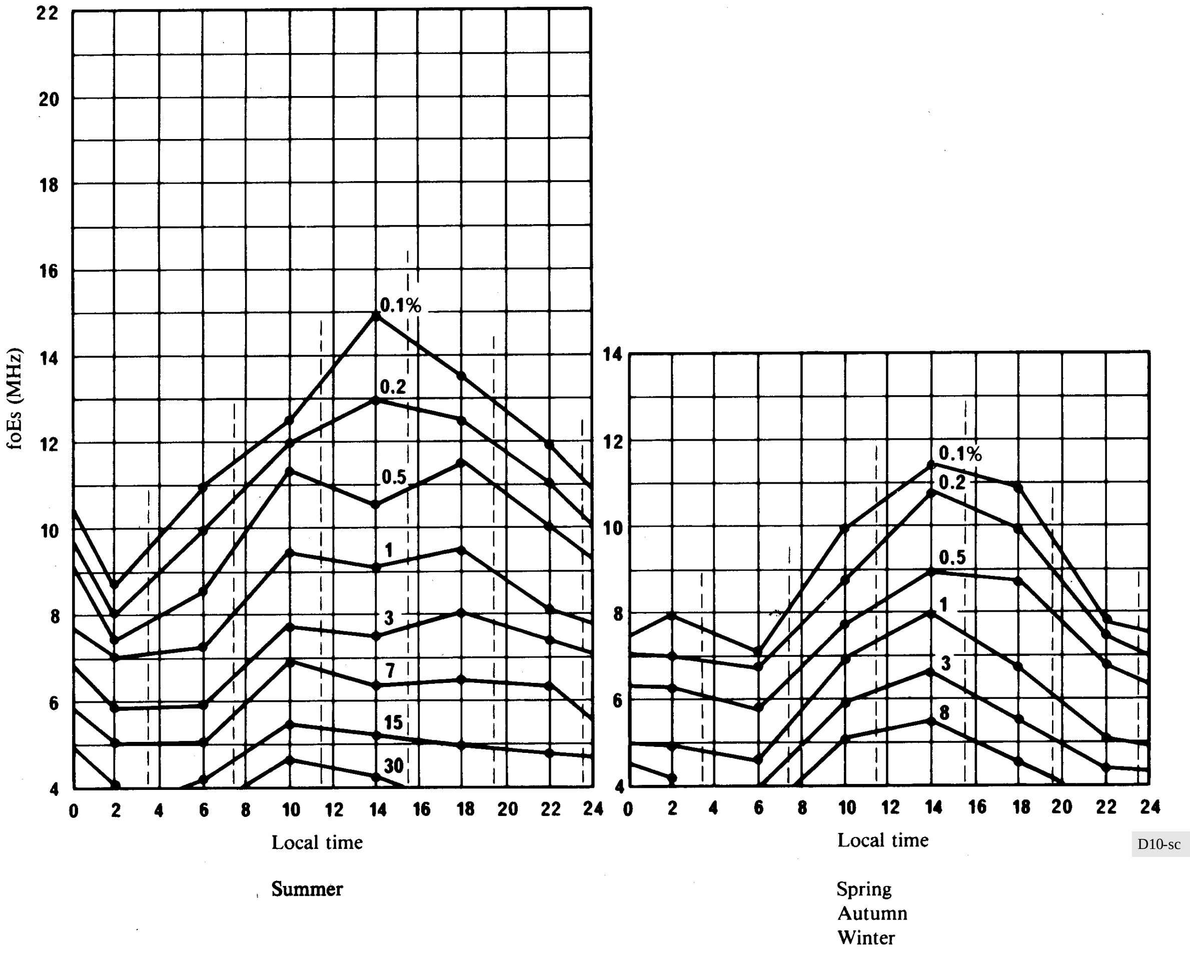

FIGURE 10 – *Values of foEs equalled or exceeded for the percentage of time indicated as the parameter on the curve during time blocks shown separated by the dotted vertical lines of 4 hours for region D (South America)*

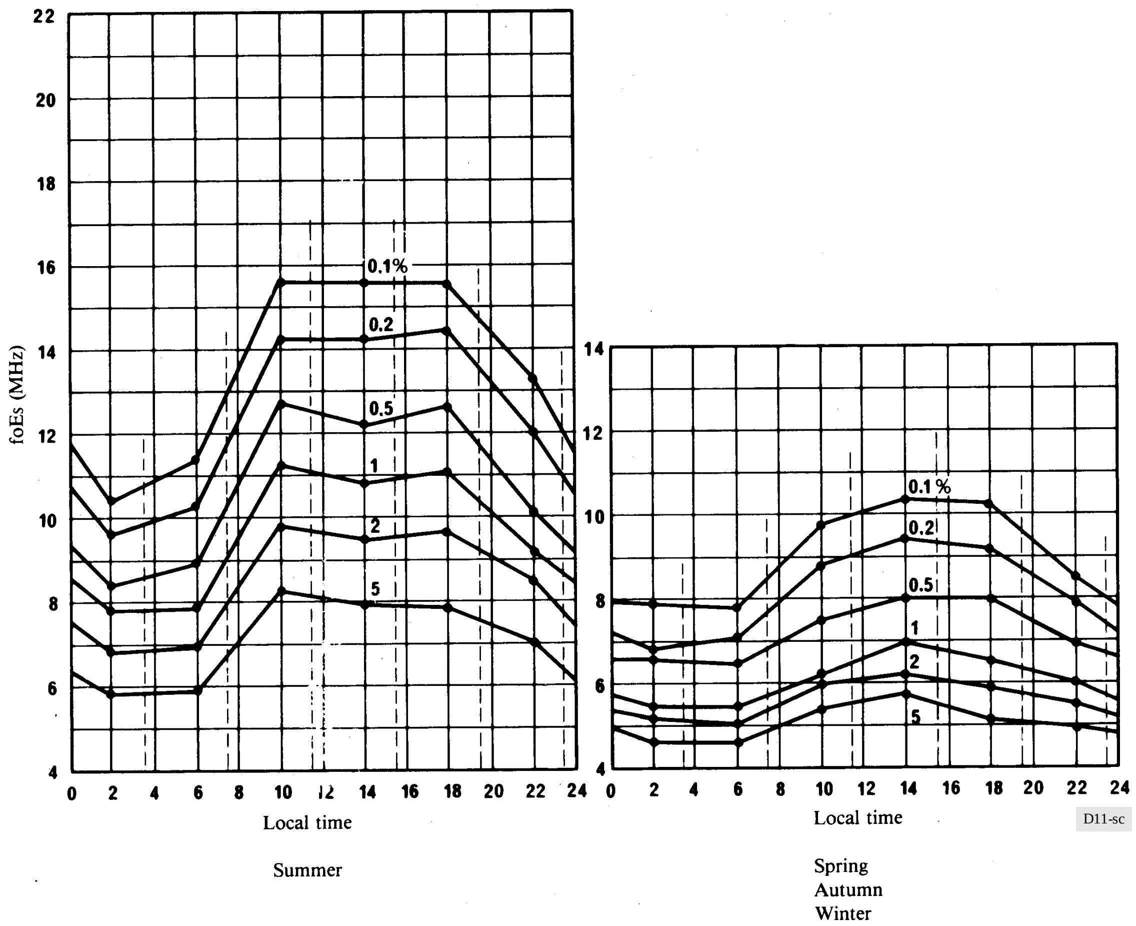

FIGURE 11 – *Mean values of foEs equalled or exceeded for the percentage of time indicated as the parameter on the curve during time blocks shown separated by the dotted vertical lines of 4 hours for regions A, B, C and D*

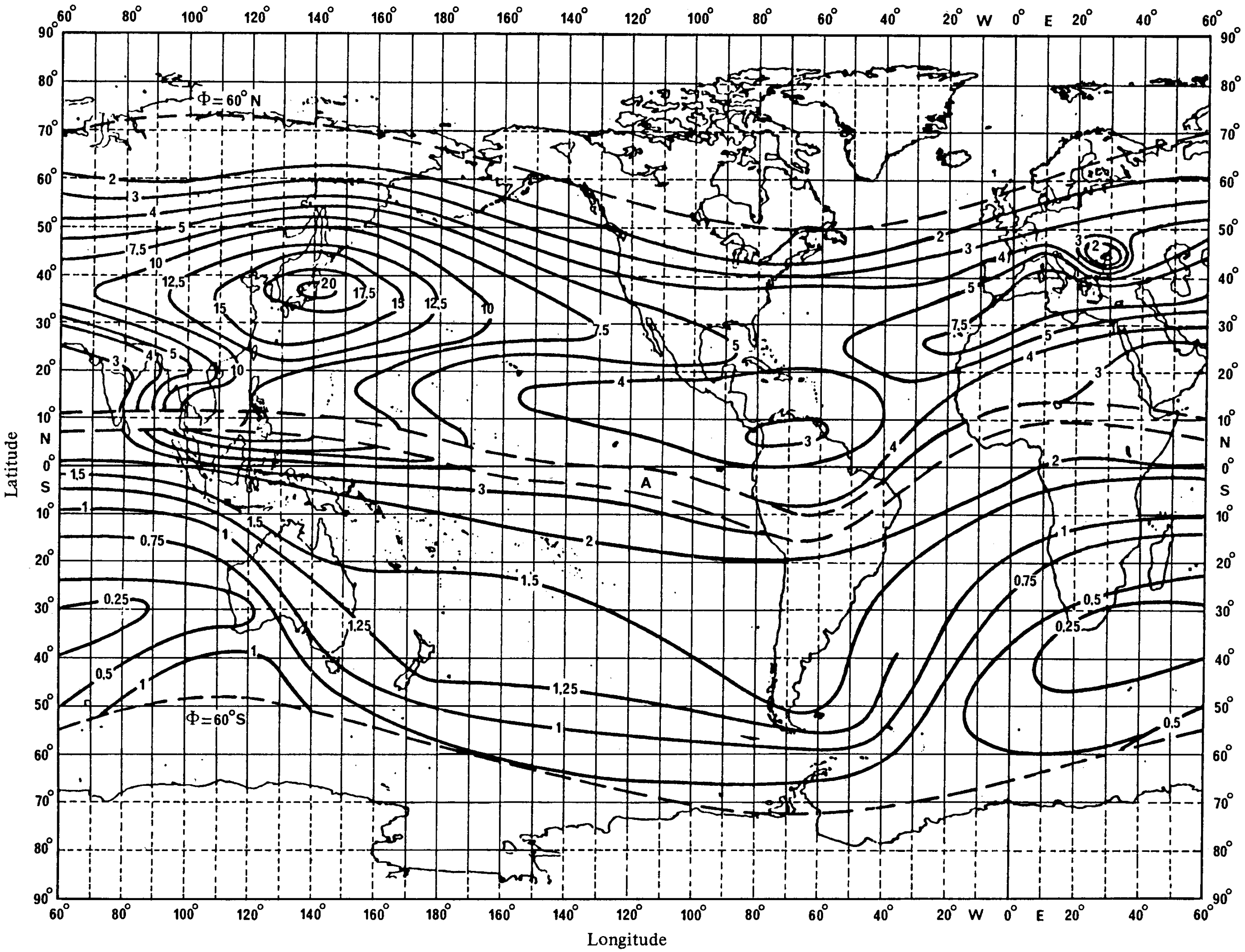

FIGURE 12 – *Percentage of time for which sporadic E (foEs) equals or exceeds 7 MHz at vertical incidence in the mid-latitude zones for the months May, June, July and August*

D12-sc

A: low latitude region (see § 4)

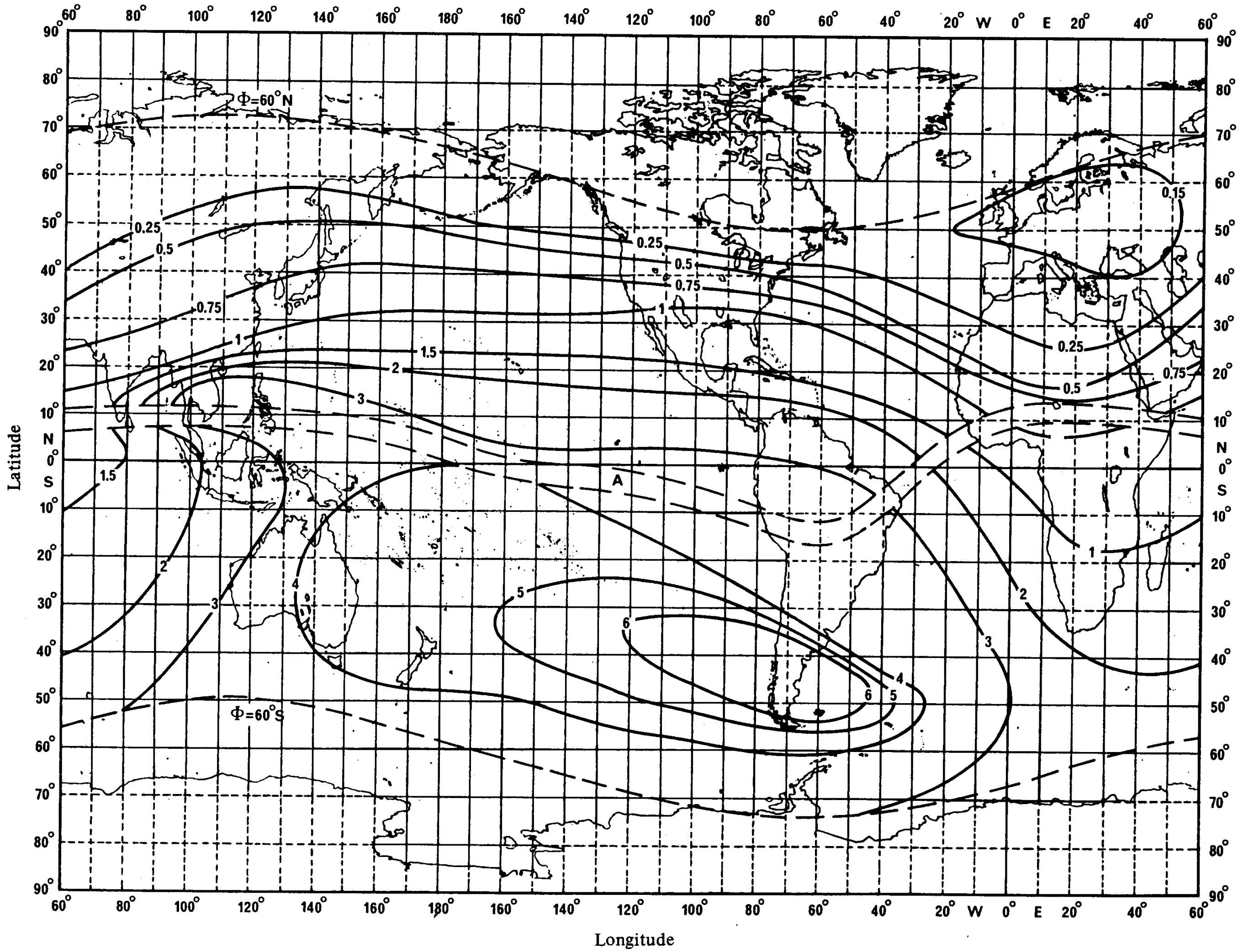

FIGURE 13 – *Percentage of time for which sporadic E (foEs) equals or exceeds 7 MHz at vertical incidence in the mid-latitude zones for the months November, December, January and February*

A: low latitude region (see § 4)

D13-sc

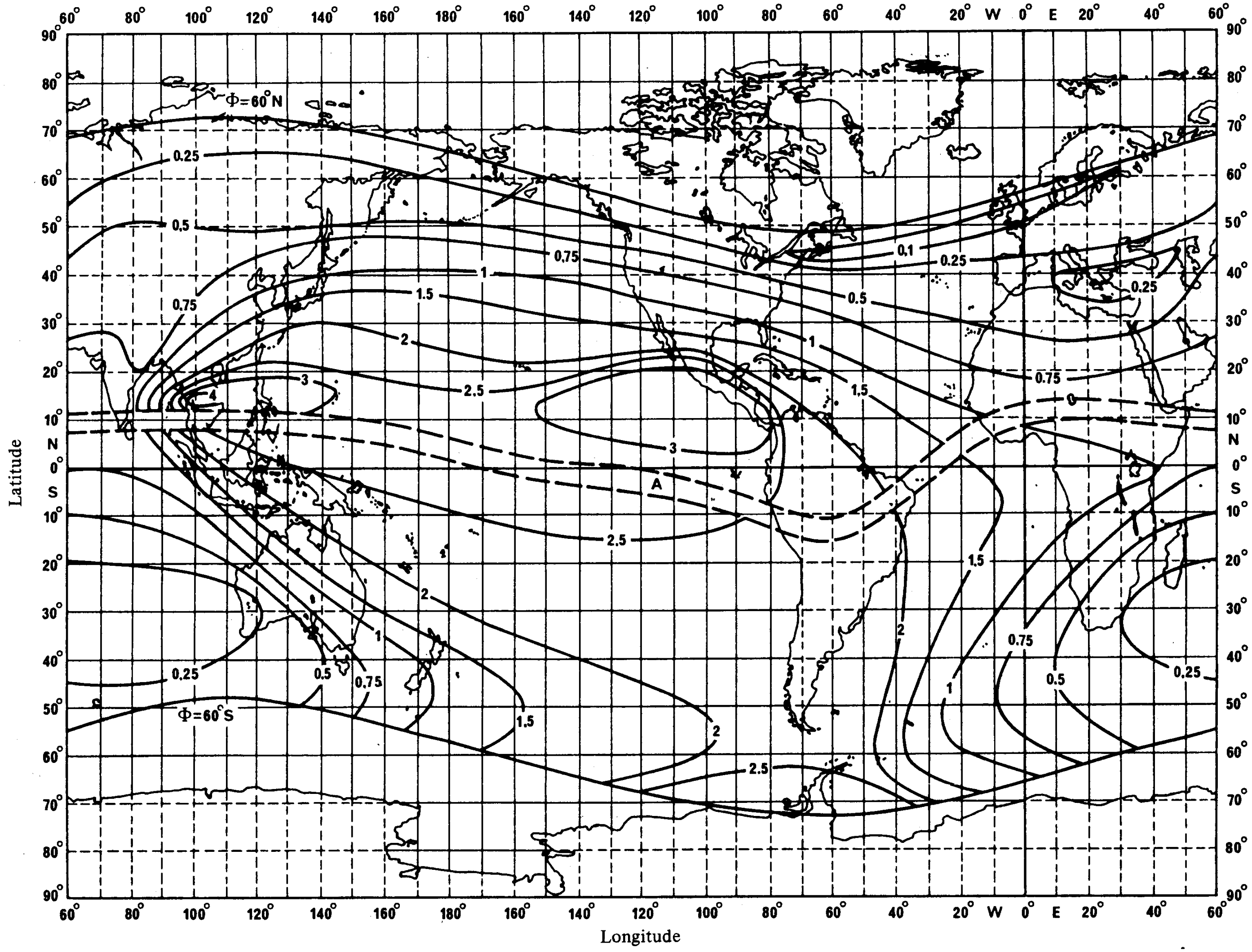

FIGURE 14 – *Percentage of time for which sporadic E (foEs) equals or exceeds 7 MHz at vertical incidence in the mid-latitude zones for the months March, April, September and October*

A: low latitude region (see § 4)

D14-sc

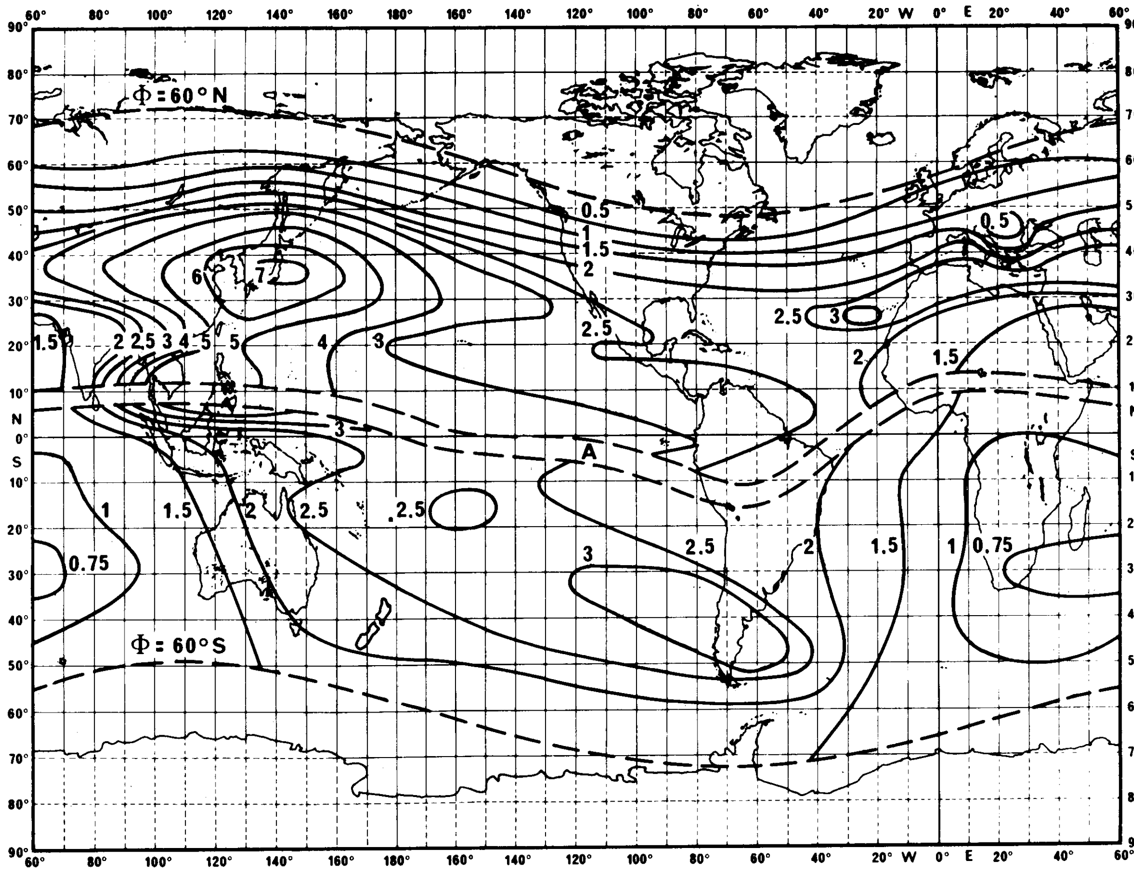

FIGURE 15 – *Percentage of time for which sporadic E (foEs) equals or exceeds 7 MHz at vertical incidence in the mid-latitude zones during the 12 months of the year*

A: low latitude region (see § 4)

D15-sc

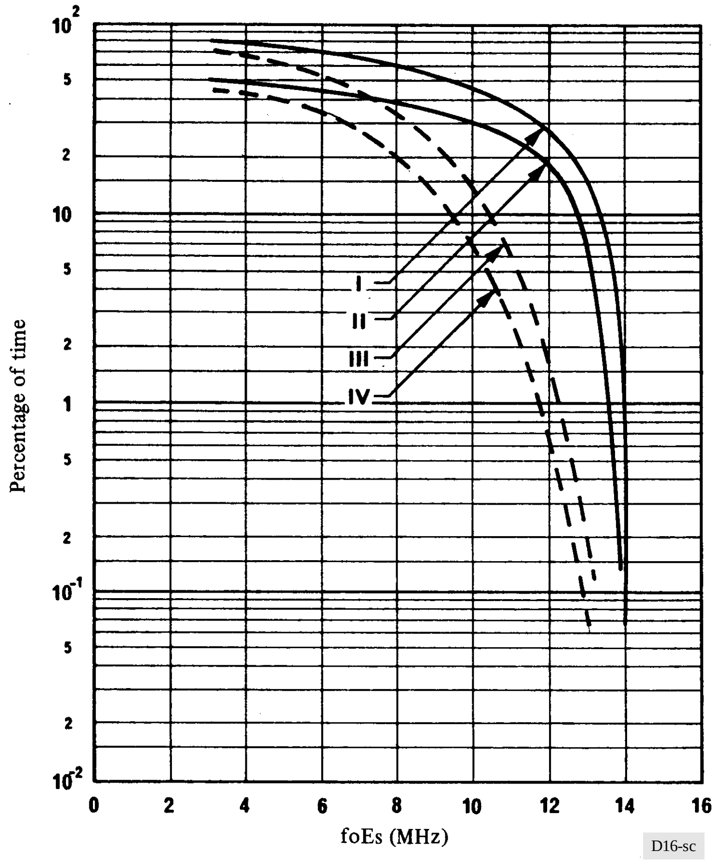

FIGURE 16 – *Values of foEs equalled or exceeded for indicated percentage of time*

Region E: Equatorial Asia (±6° dip latitude)

I: maximum solar activity years (0600-1800 h). Annual average

II: maximum solar activity years. Annual average

III: median and low solar activity years (0600-1800 h). Annual average

IV: median and low solar activity years. Annual average

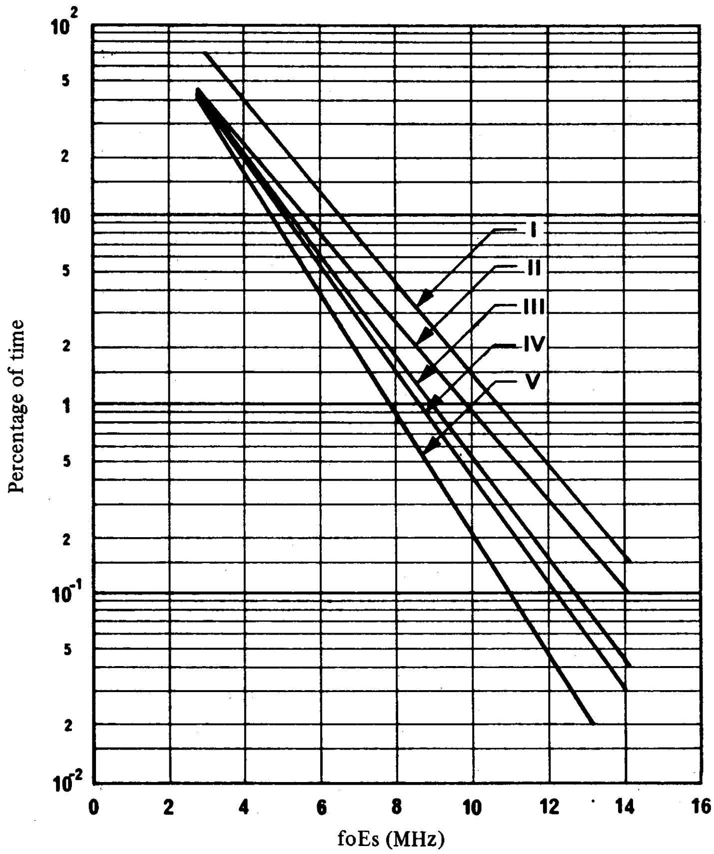

FIGURE 17 – *Values of foEs equalled or exceeded for indicated percentage of time*

Region E: Sub-equatorial Asia (between ±6° and ±20° dip latitude)
I: summer (0600-1800 h)
II: summer
III: annual average
IV: equinox
V: winter

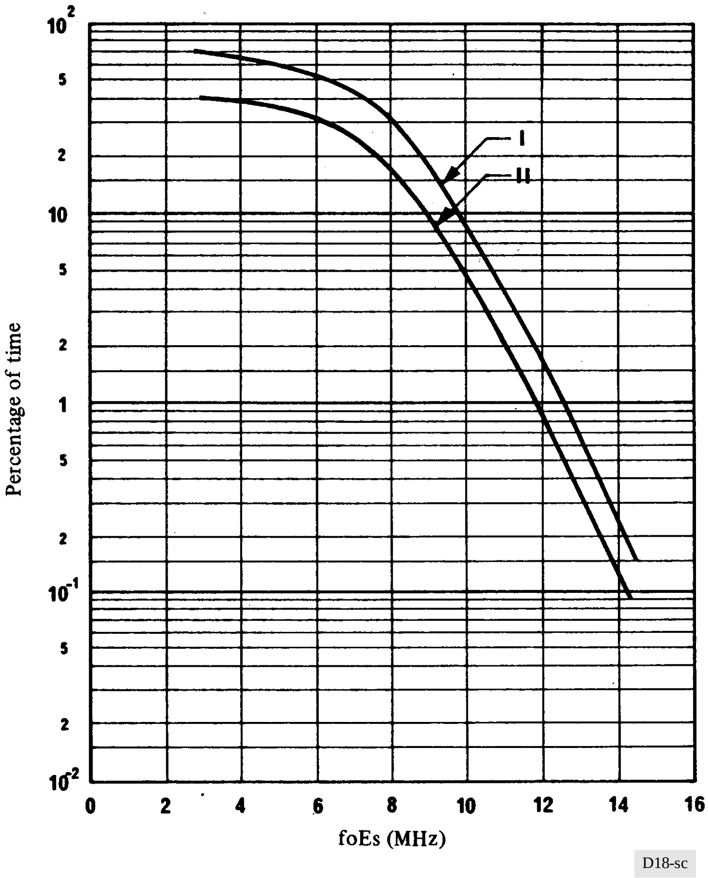

FIGURE 18 – *Values of foEs equalled or exceeded for indicated percentage of time*

Region F: Equatorial Africa (±6° dip latitude)
I: annual average (0600-1800 h)
II: annual average

Note. – Differences between seasons are smaller than the annual average error. Also there is no significant change with solar activity.

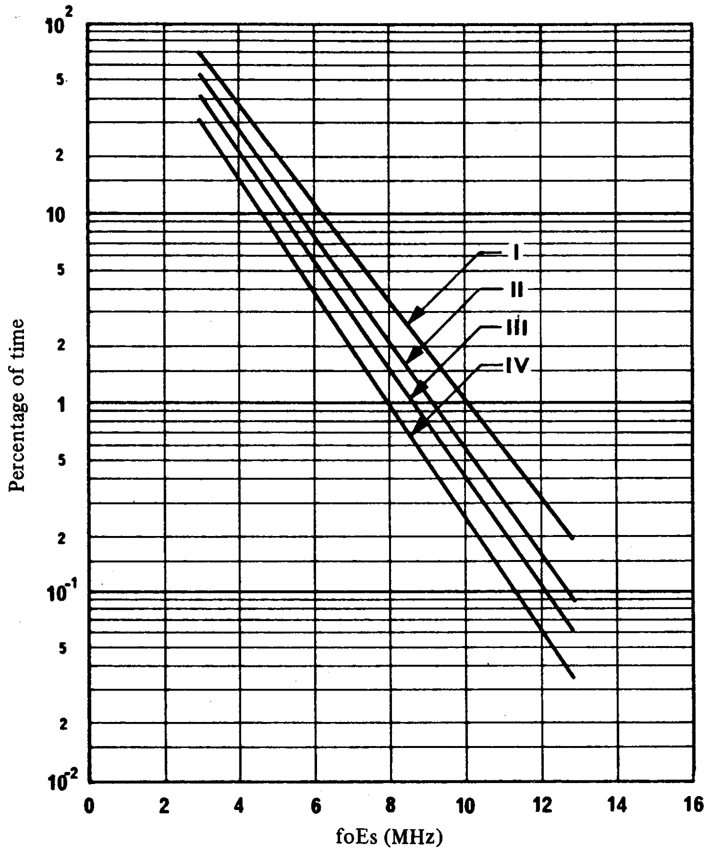

FIGURE 19 – *Values of foEs equalled or exceeded for indicated percentage of time*

Region F: Sub-equatorial Africa (between ±6° and ±20° dip latitude)
I: summer (0600-1800 h)
II: summer
III: annual average and equinox
IV: winter

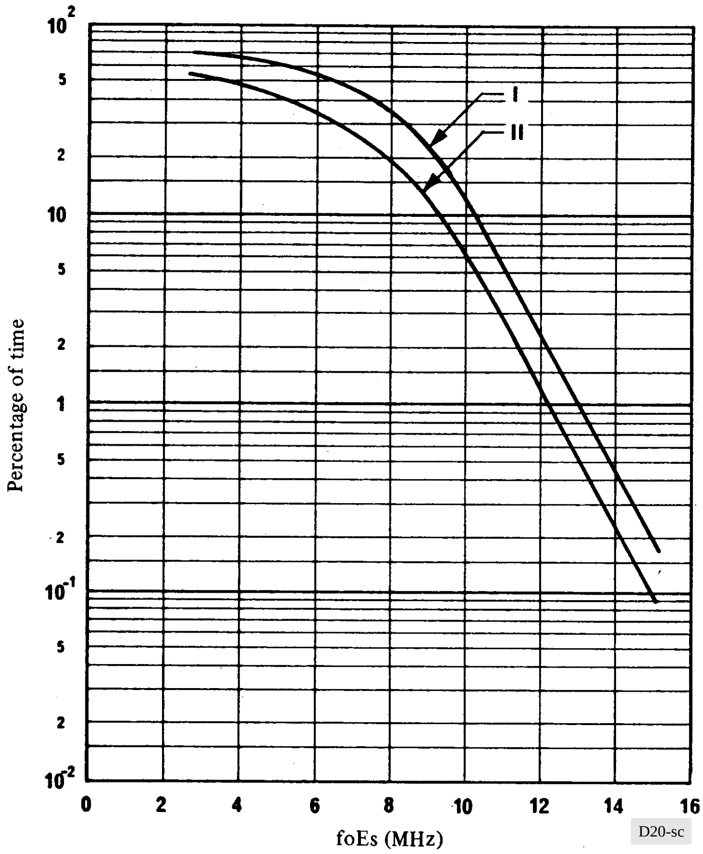

FIGURE 20 – *Values of foEs equalled or exceeded for indicated percentage of time*

Region G: Equatorial America (±6° dip latitude)
I: annual average (0600-1800 h)
II: annual average

Note. – Differences between seasons are smaller than the annual average error.

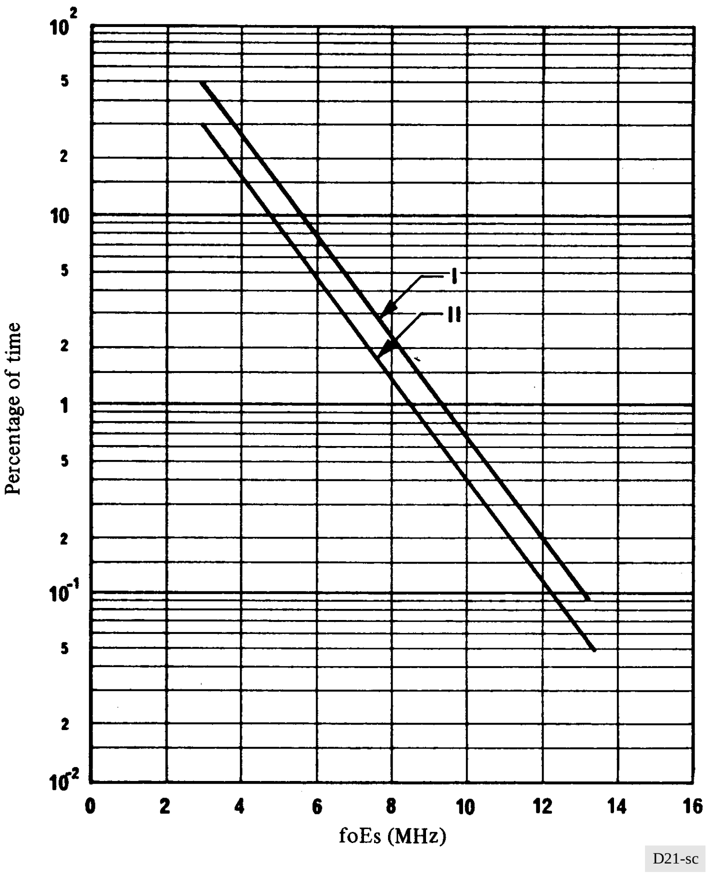

FIGURE 21 – *Values of foEs equalled or exceeded for indicated percentage of time*

Region G: Sub-equatorial America (between ±6° and ±20° dip latitude)
I: annual average (0600-1800 h)
II: annual average

Note. – Differences between seasons are smaller than the annual average error.

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