International Telecommunication Union

ITU-R
Radiocommunication Sector of ITU

Recommendation ITU-R P.534-6
(09/2021)

Method for calculating sporadic-E field strength

P Series
Radiowave propagation

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Note: *This ITU-R Recommendation was approved in English under the procedure detailed in Resolution ITU-R 1.*

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RECOMMENDATION ITU-R P.534-6

Method for calculating sporadic-E field strength

(Question ITU-R 221/3)

(1978-1982-1986-1990-1999-2012-2021)

The ITU Radiocommunication Assembly,

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 1 to this Recommendation has been proved to be practical and reliable;

c) that there exists no other practical method,

recommends

1 that the calculation method in Annex 1 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 1 is used in these regions.

Annex 1

Propagation by sporadic E

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 4 000 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 ITU-R P.533 for regular-layer propagation.) The data provided by the Recommendation are restricted to geomagnetic latitudes between ±60°.

In the equatorial region some sky-wave paths of medium distance propagation (500-2 000 km), clearly indicate Es propagation, which must be distinguished from the much more important effects of trans-equatorial propagation (TEP) in the area. 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 field strength or receiver input voltage can be expressed as follows:

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

$$E_0 = 104.8 - 20 \log l \qquad \text{dB} \tag{1a}$$

$$V = V_0 + P + G_t + G_r - L_t - L_r - \Gamma \tag{2}$$

$$V_0 = 133 - 20 \log l - 20 \log f \tag{2a}$$

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

V: median voltage developed across receiver input terminals (dB(μV))

V_0: theoretical inverse distance receiver input voltage, for 1 kW radiated power and isotropic transmitting and receiving antenna matched to 50 Ω feeder for a signal frequency of f (MHz)

P: transmitter power (dB(1 kW))

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

G_r: gain of the receiving antenna relative to an isotropic antenna, (dB)

L_t: losses including feeder loss and mismatch loss of the transmitting antenna, (dB)

L_r: losses including feeder loss and mismatch loss of the receiving antenna, (dB)

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

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

f: signal frequency (MHz).

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

$$\Gamma_{(1\,hop)}\,(d) \;=\; \left\{ \frac{40}{1 \,+\, \left(\dfrac{d}{130}\right) \,+\, \left(\dfrac{d}{250}\right)^2} \;+\; 0.2\left(\frac{d}{2\,600}\right)^2 \right\} \left(\frac{f}{\text{foEs}}\right)^2 \;+\; \exp\left(\frac{d \;-\; 1\,660}{280}\right) \tag{3}$$

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

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

and

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

$$l \;=\; 2\left\{R_0^{\,2} \;+\; (R_0 \;+\; h)^2 \;-\; 2R_0(R_0 \;+\; h)\;\cos(d\,/(2R_0))\right\}^{1/2} \tag{5}$$

where:

R_0: effective radius of the Earth, 8500 km

h: height of Es layer, 120 km

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

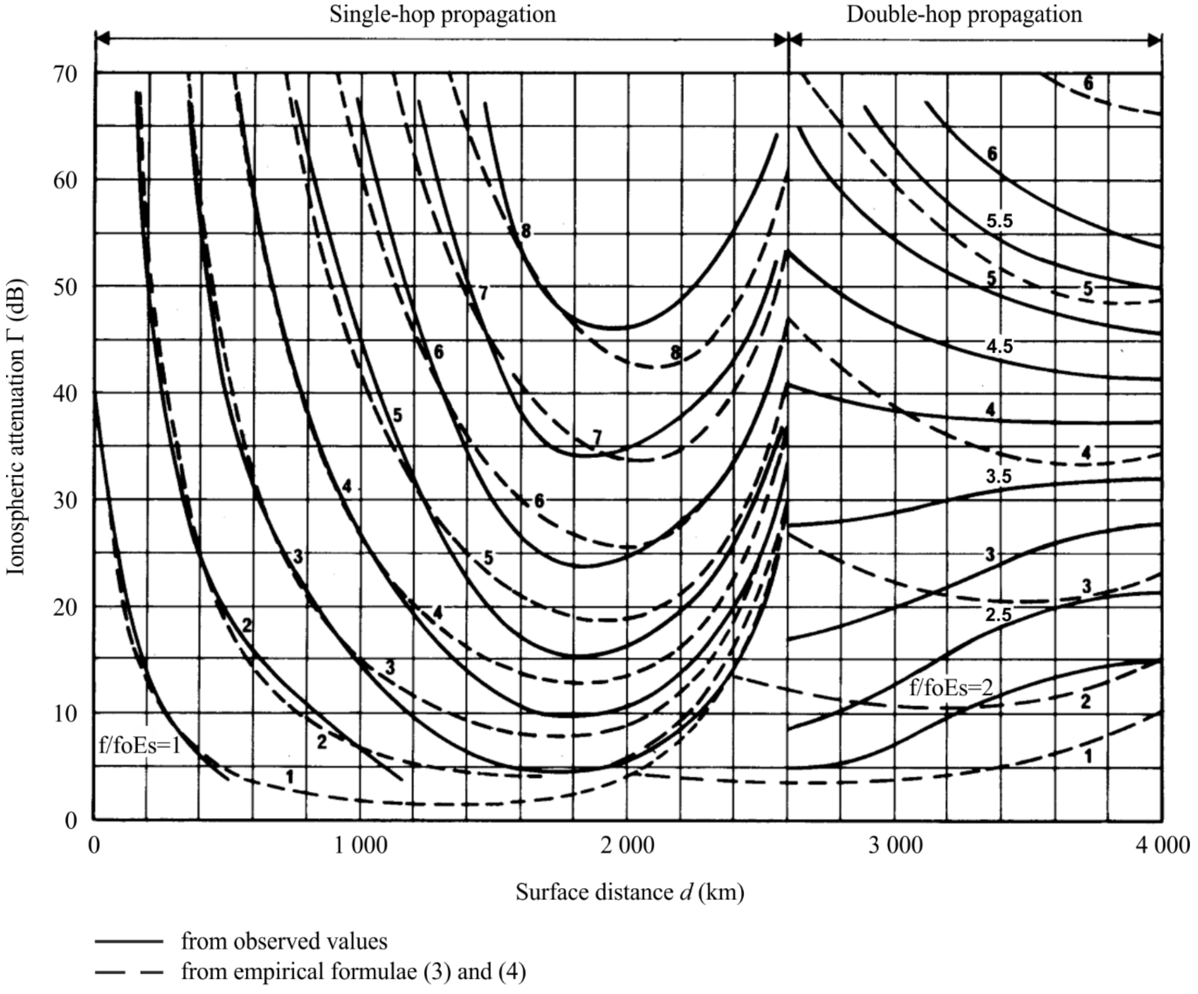
f: signal frequency (MHz)

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



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3 A procedure for calculating sporadic-E field strength

A procedure for calculating Es field strength is as follows:

Step 1: calculate a value of E_0 (or V_0) corresponding to given value of *l* using equation (1a) (or equation (2a)).

Step 2a: (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.

Step 2b: (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.

Step 3: calculate *f*/foEs.

Step 4: using the broken 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).

Step 5: calculate the predicted value of E (or V) by equation (1) (or (2)), using given values of P, G_t, G_r, L_t, L_r 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 in Recommendation ITU-R P.1240, 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 characteristics 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 to 15. 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: 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.

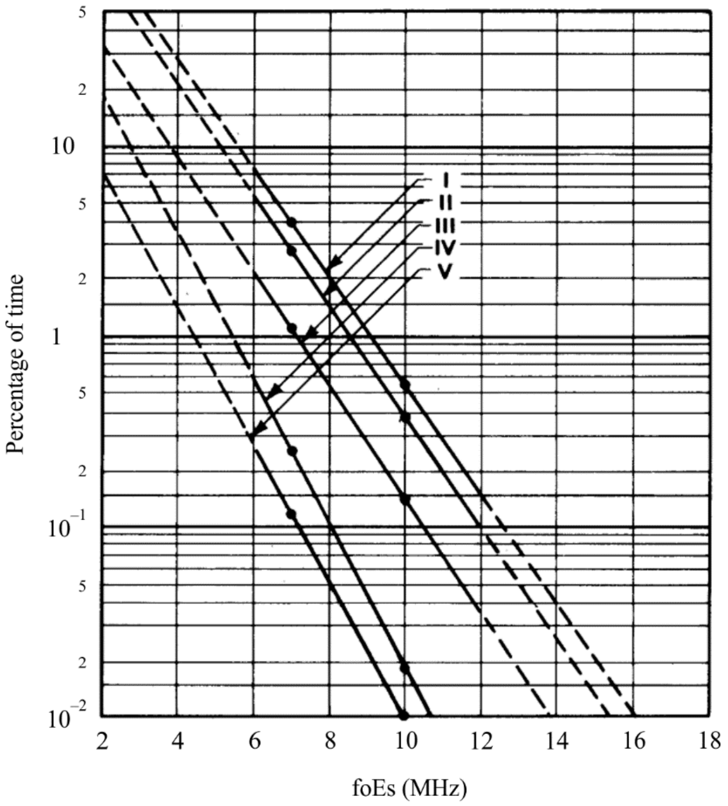
Figures 7 to 11 exhibit diurnal variations of occurrence of foEs in a time block of 4 h in the above four regions for the summer and non-summer months, according to their distinctive characteristics. It is noticeable that a definite minimum of foEs is observed shortly after midday in regions B and C, 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 h.

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

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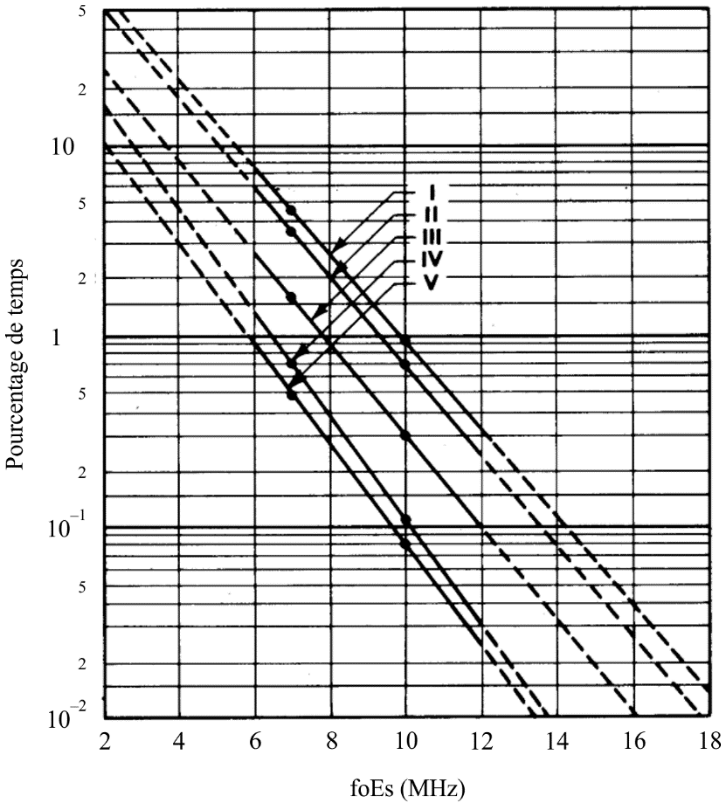
FIGURE 3

Values of foEs equalled or exceeded for indicated percentage of time for region B



Region B: Amérique du Nord
I: de mai à août (8 h 00-23 h 00)
II: de mai à août
III: moyenne annuelle
IV: mars, avril, septembre et octobre
V: de novembre à février

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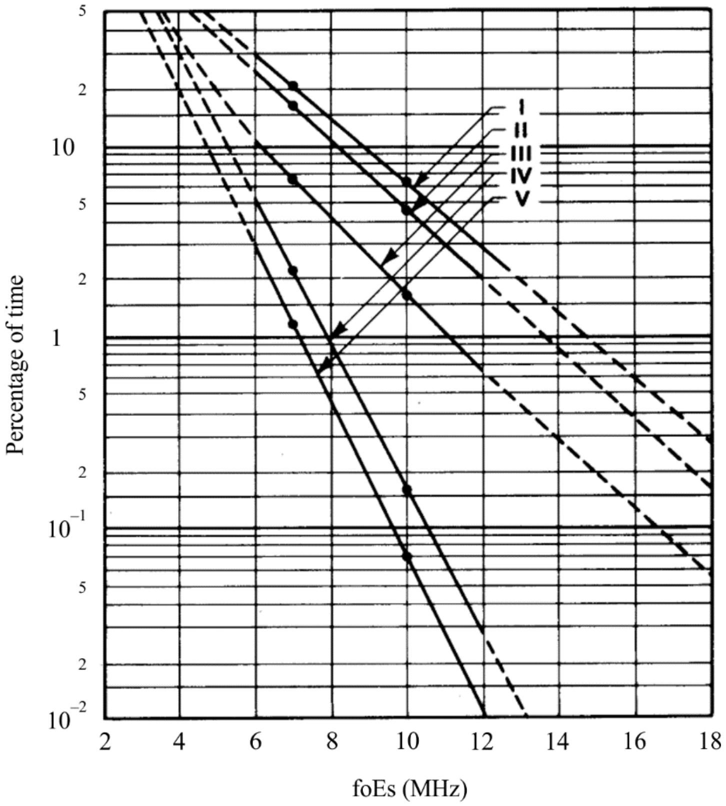
FIGURE 4

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

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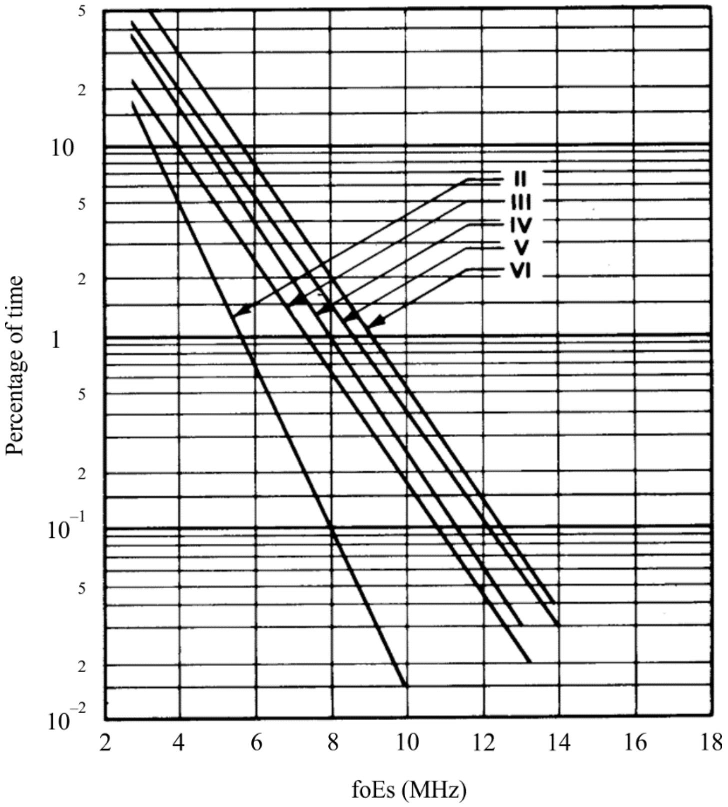
FIGURE 5

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)

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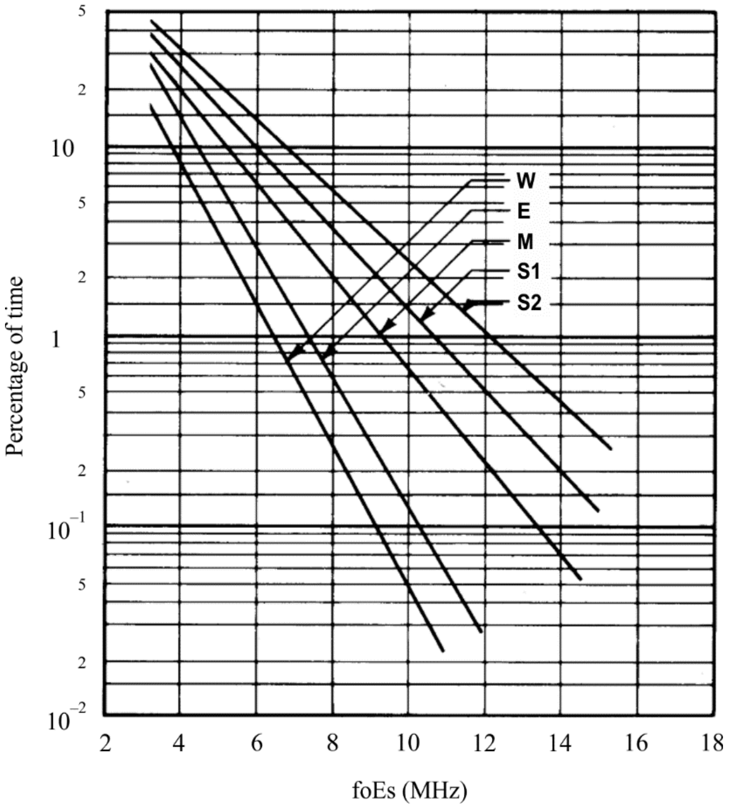
FIGURE 6

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

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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)

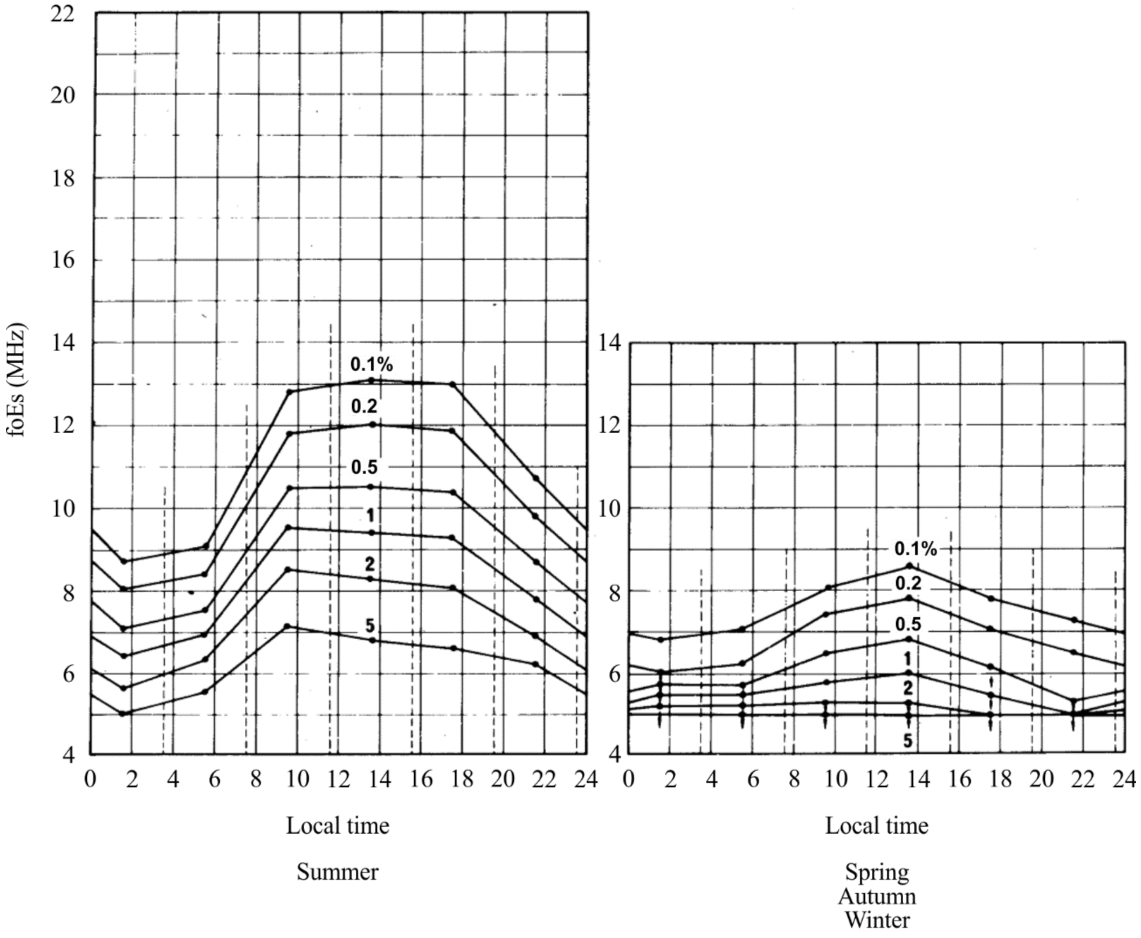

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FIGURE 8

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)

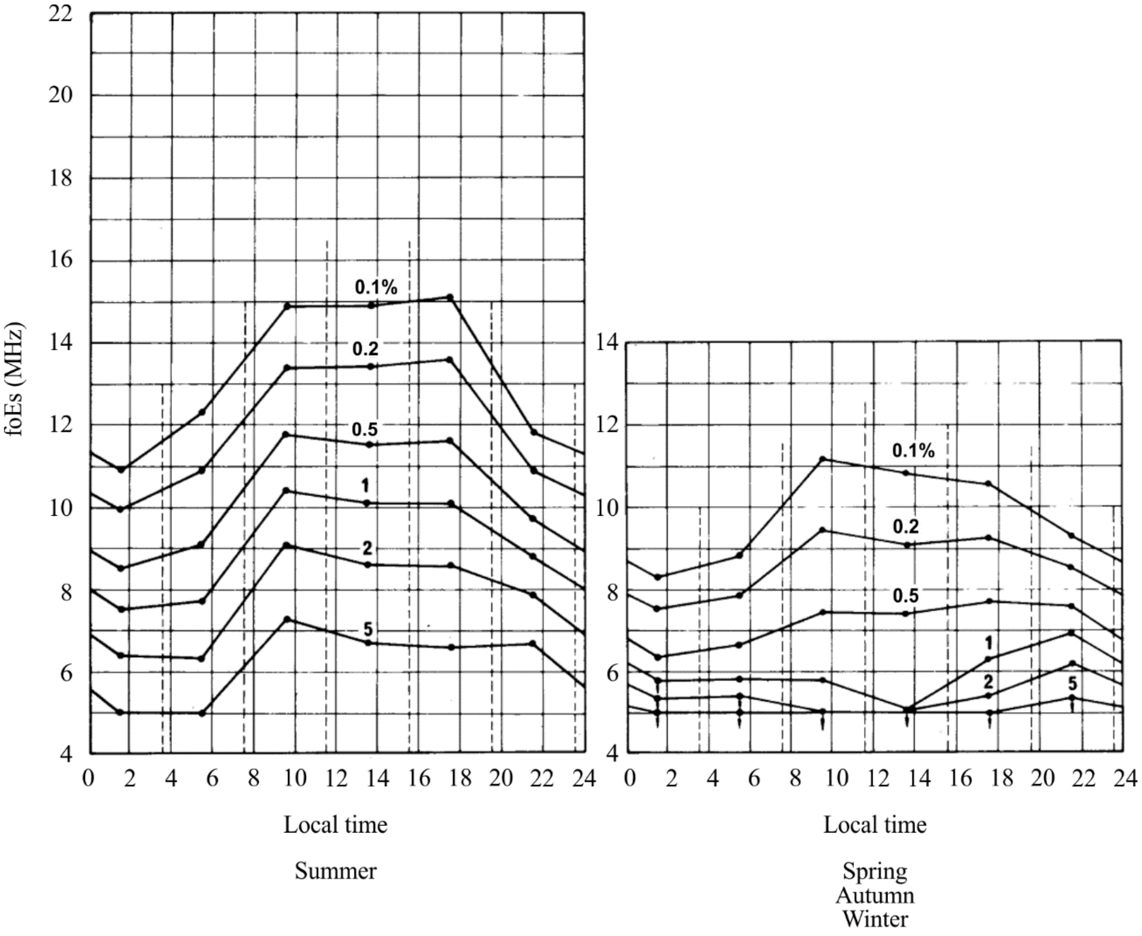

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FIGURE 9

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 C (Asia (Far East))

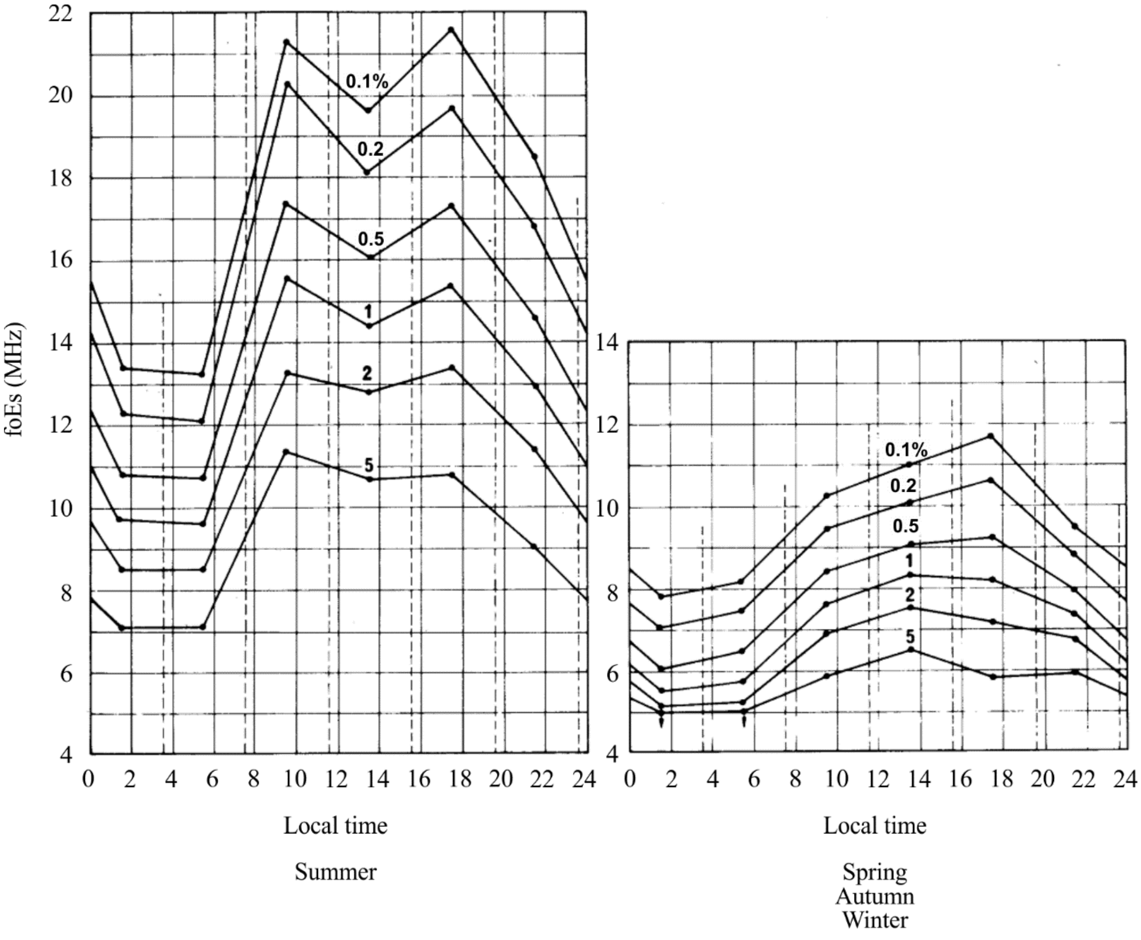

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FIGURE 10

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)

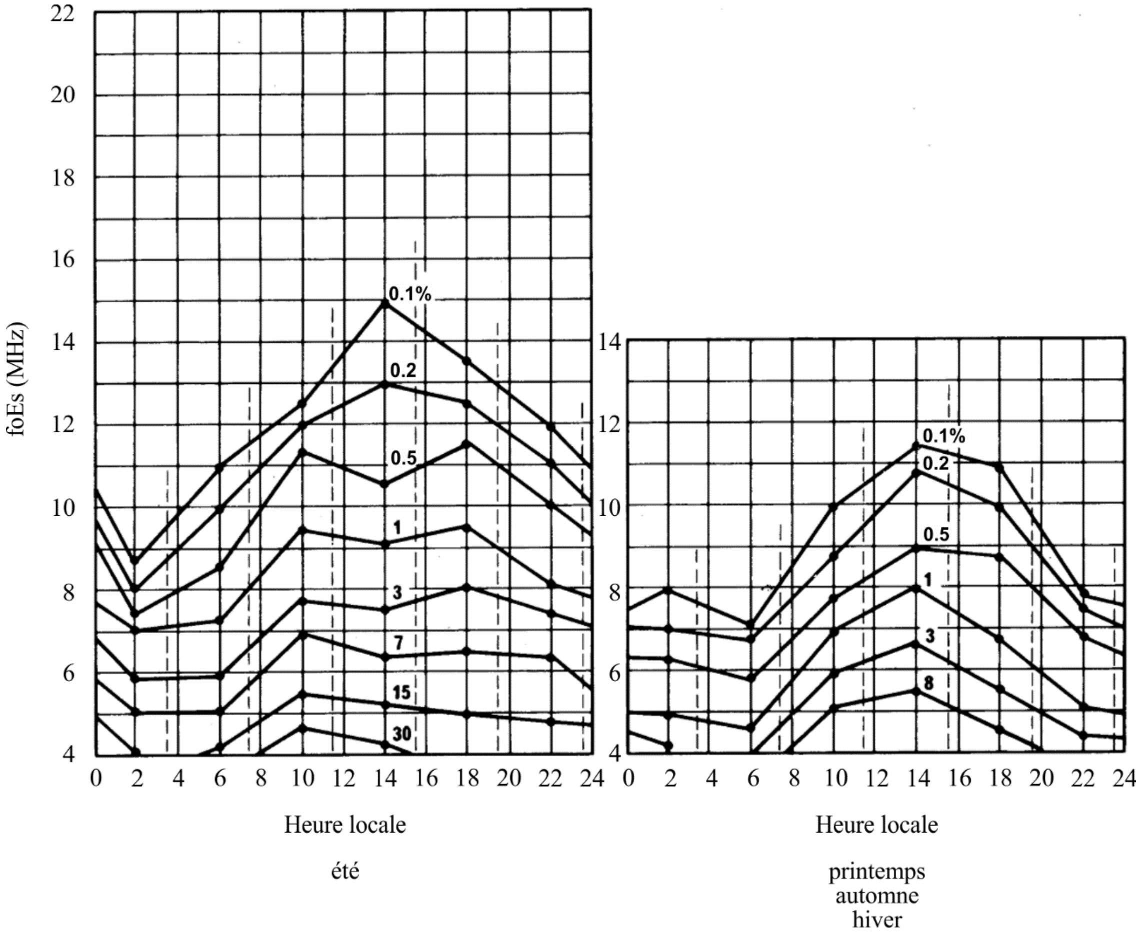

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FIGURE 11

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

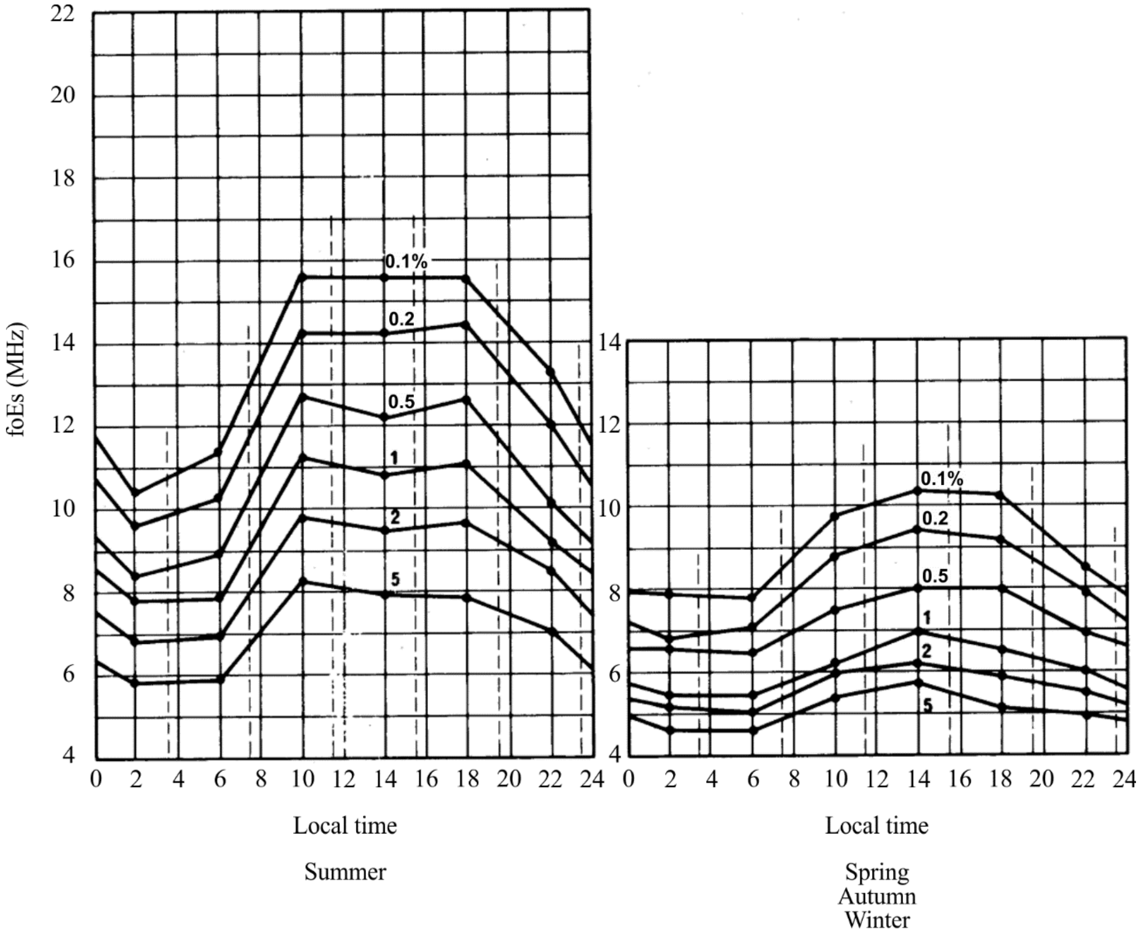

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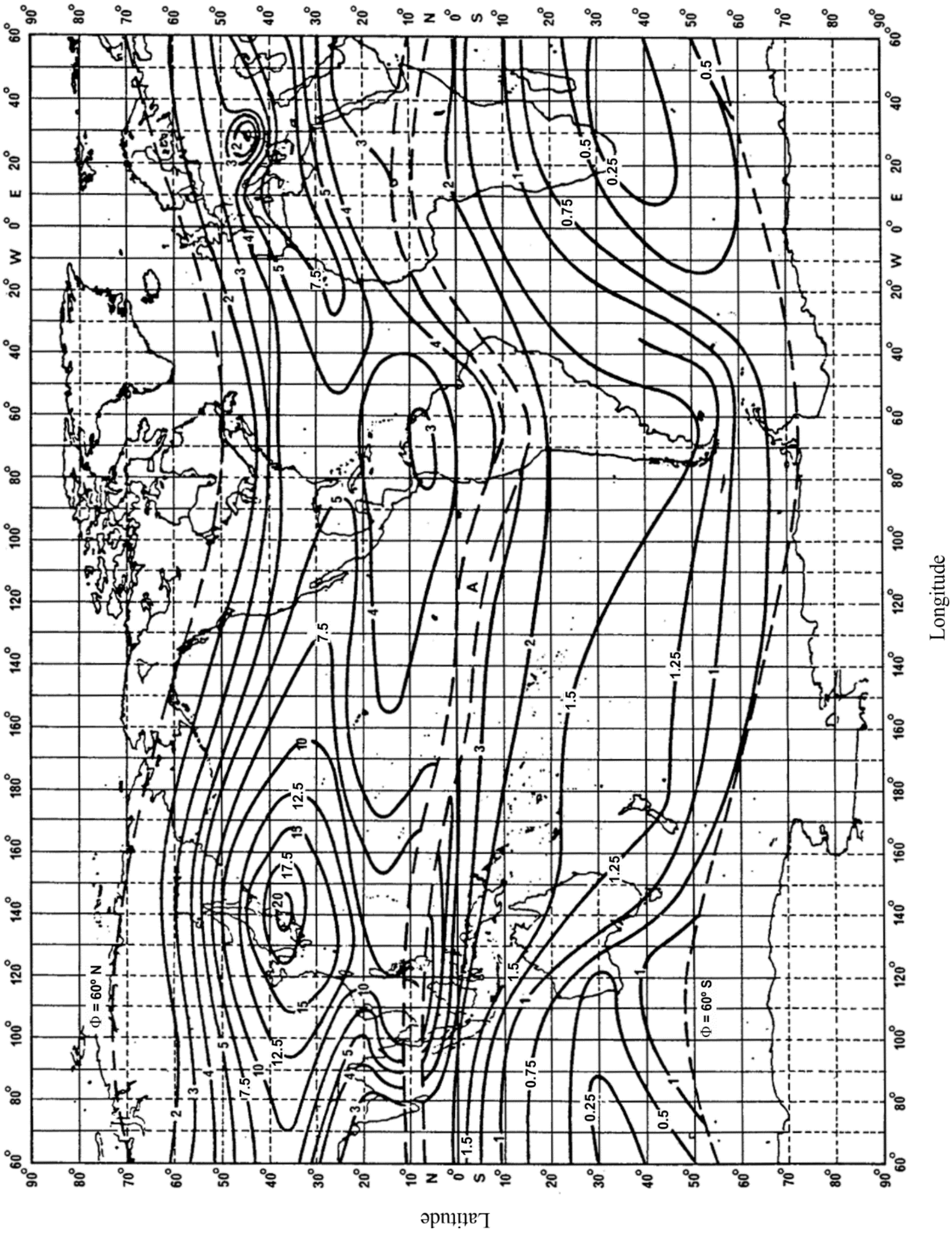
FIGURE 12

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



A: low latitude region (see § 4)

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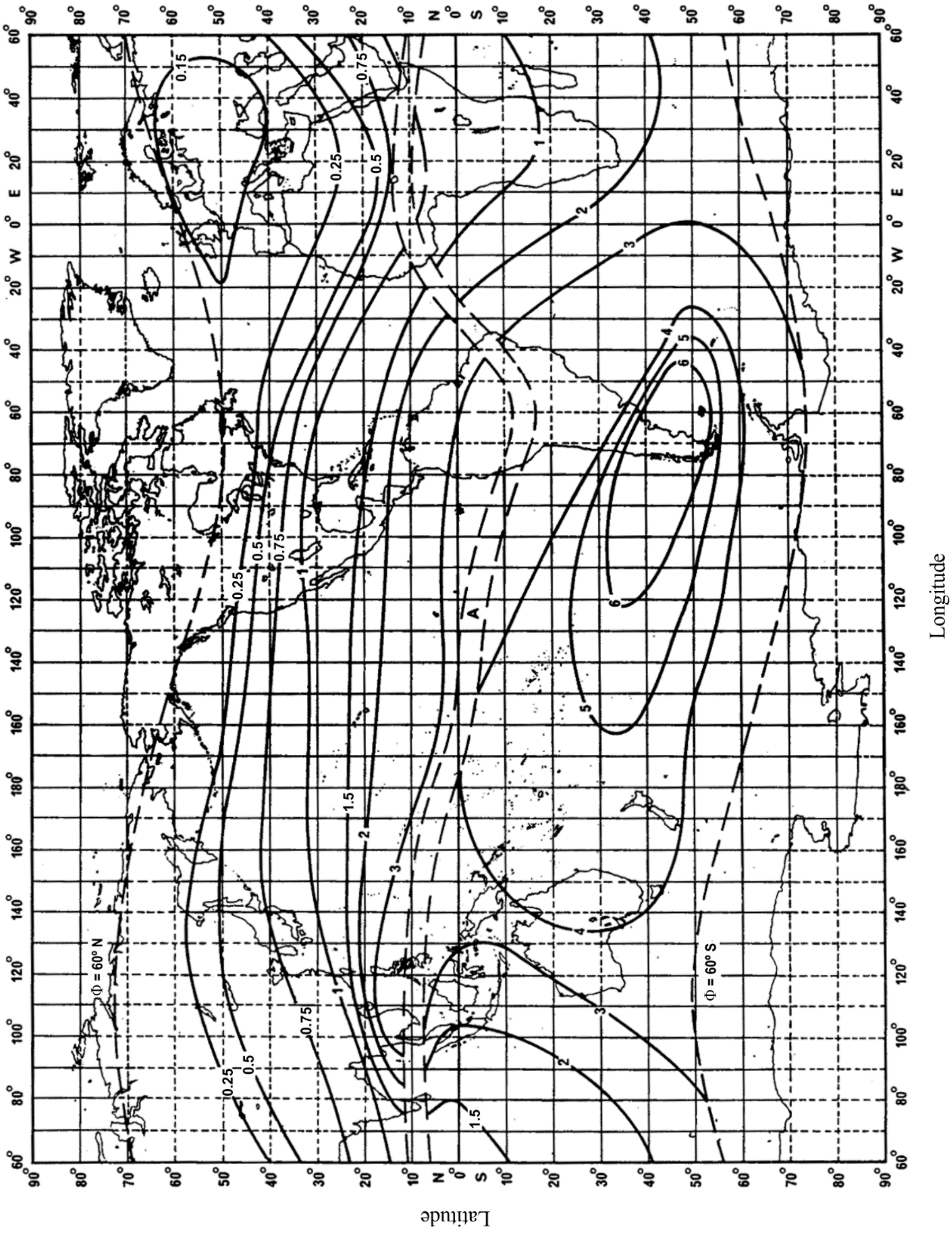
FIGURE 13

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)

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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

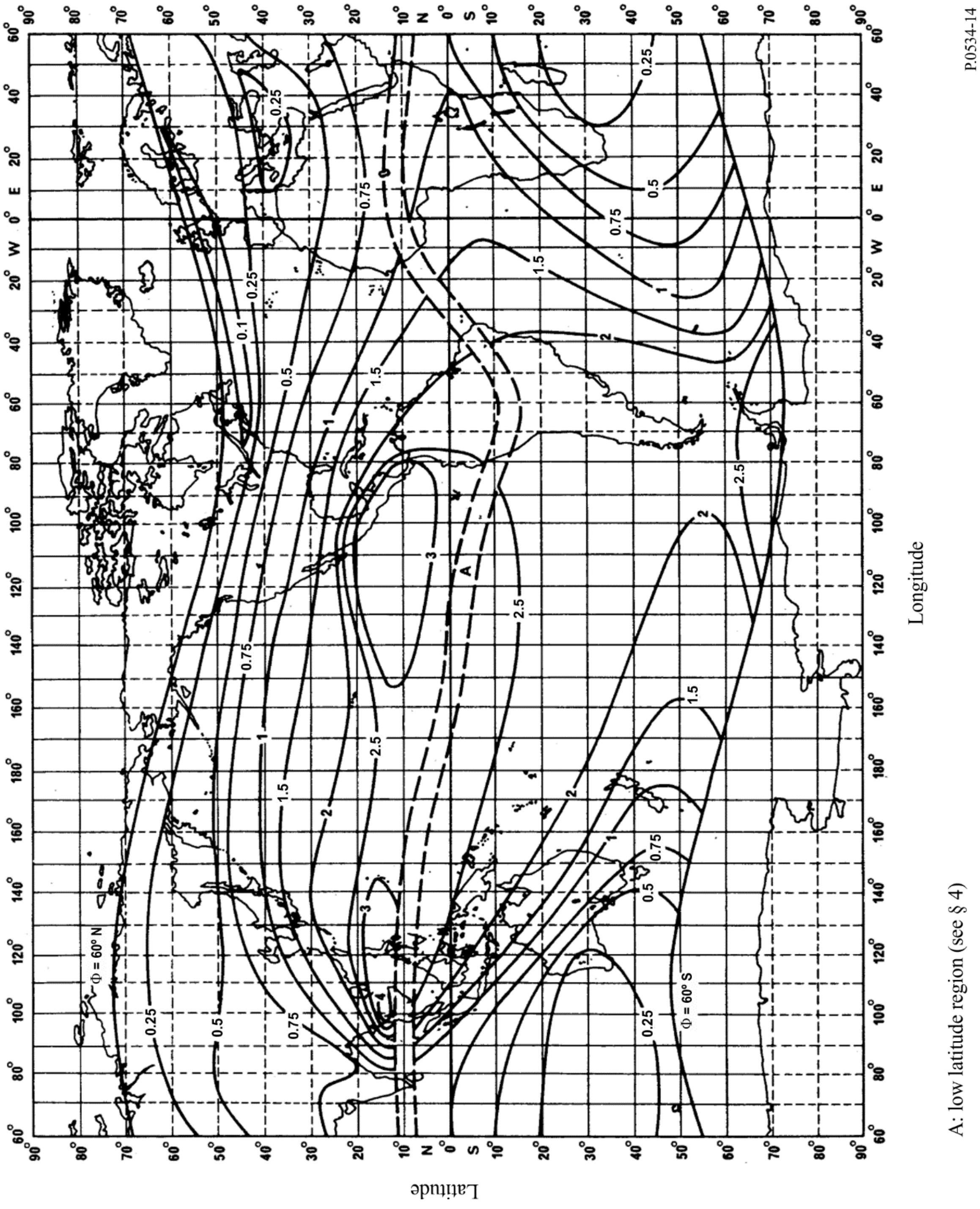
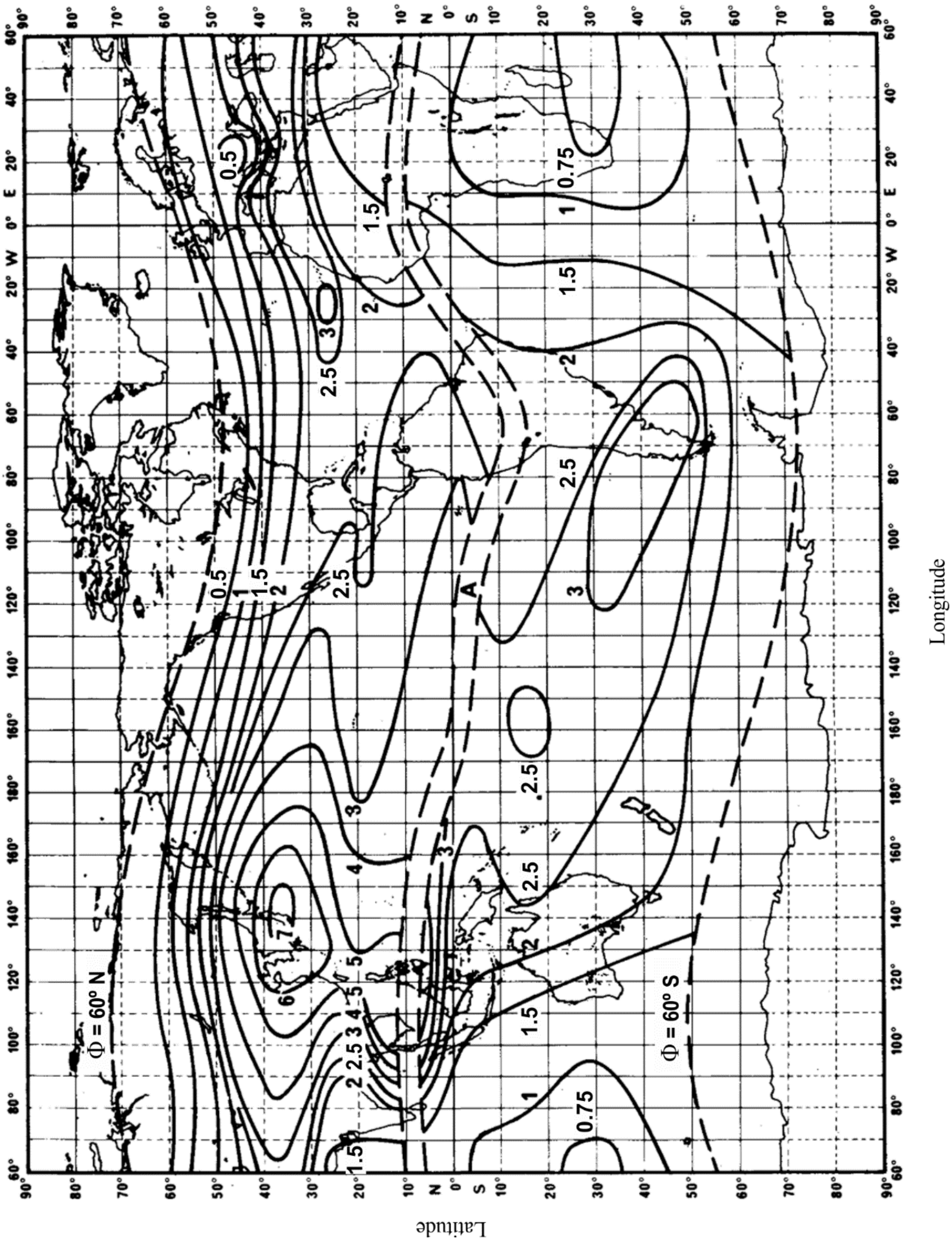


FIGURE 15

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)

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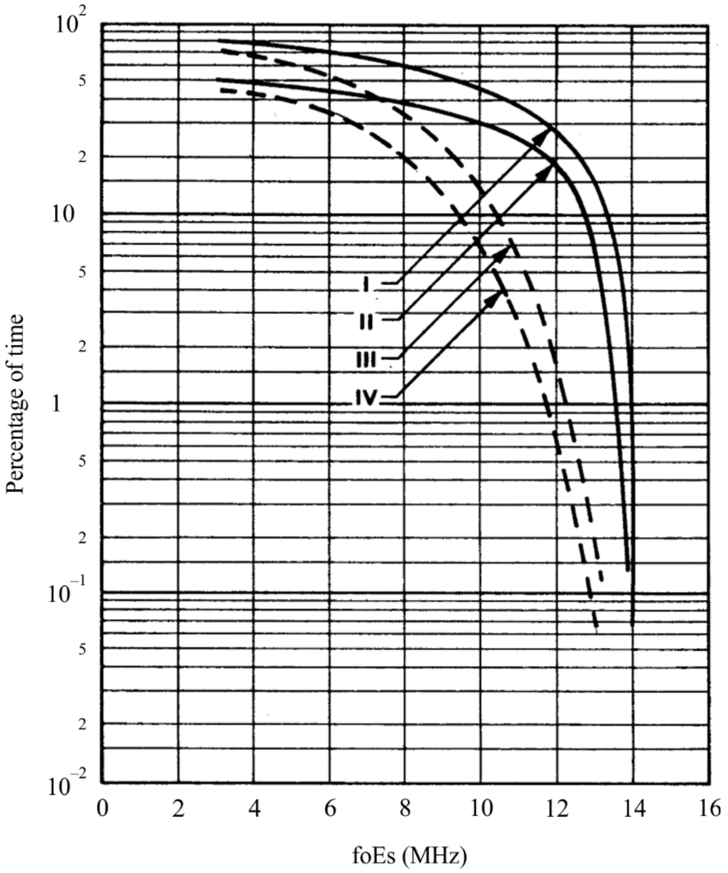
FIGURE 16

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

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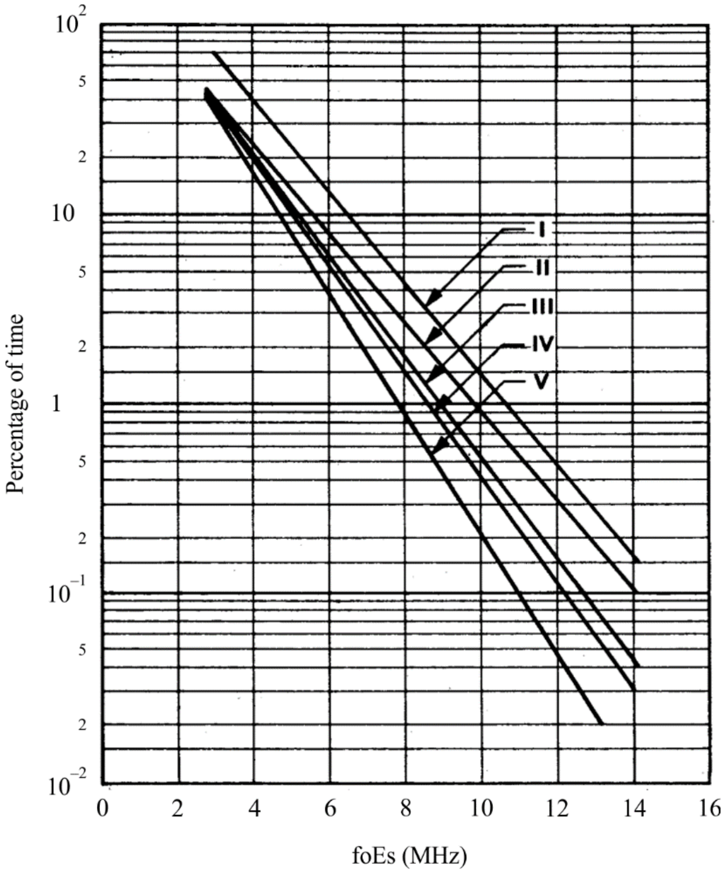
FIGURE 17

Values of foEs equalled or exceeded for indicated percentage of time



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

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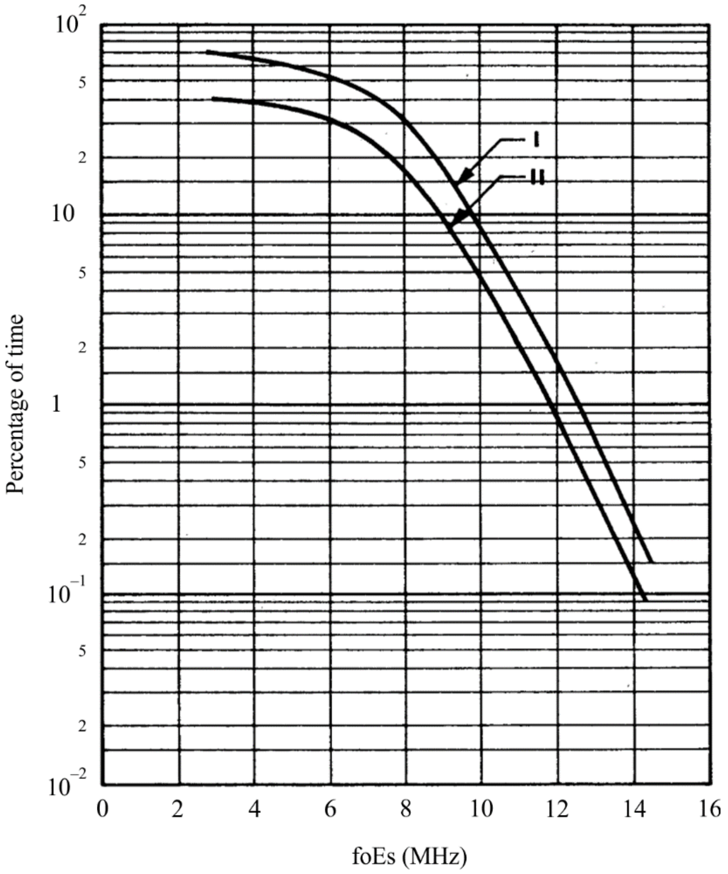
FIGURE 18

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

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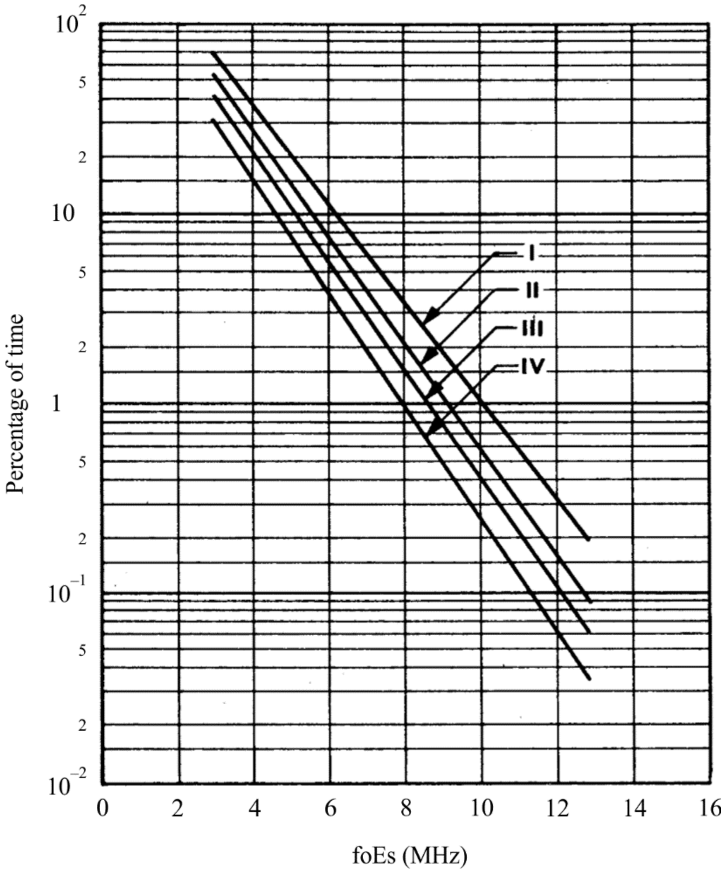
Note to Fig. 18: Differences between seasons are smaller than the annual average error. Also there is no significant change with solar activity.

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

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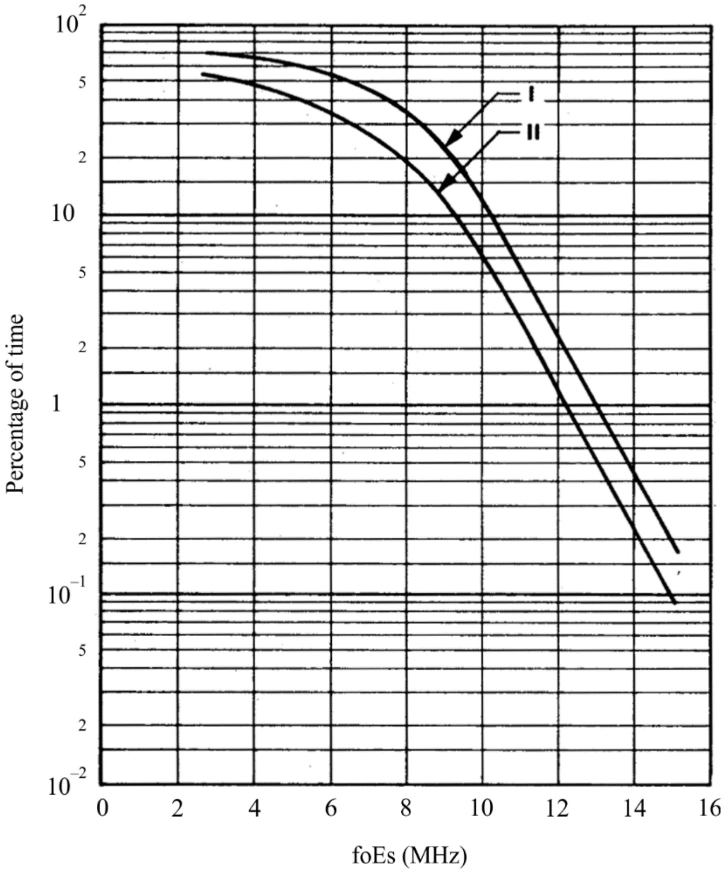
FIGURE 20

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

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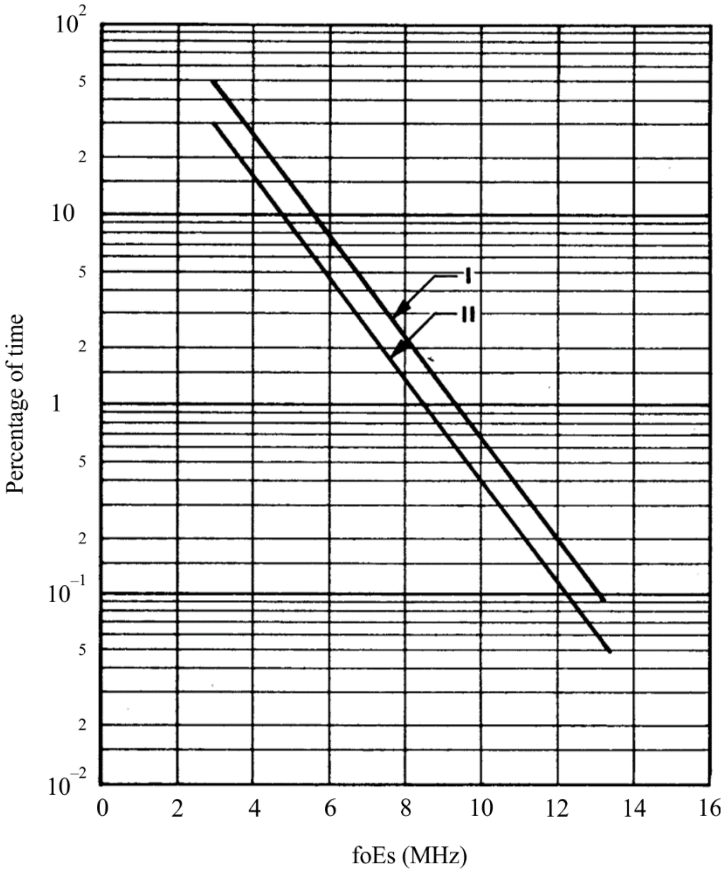
Note to Fig. 20: Differences between seasons are smaller than the annual average error.

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

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Note to Fig. 21: Differences between seasons are smaller than the annual average error.

4.3 Global maps of foEs exceeded for annual percentage times

To facilitate computer based predictions a set of maps of the critical frequency for sporadic E, foEs (MHz) not exceeded for annual average time percentages of 50%, 10%, 1% and 0.1% have been developed. These maps were based on a global data set containing long-term measurements from 101 Ionosonde stations. These are available in electronic format from ITU-R Study Group 3 website. An example of the 50% map is given in Fig. 22.

The critical frequency for sporadic E, foEs (MHz) not exceeded for annual average time percentages of 50%, 10%, 1% and 0.1%, are an integral part of this recommendation and are available as digital maps in the supplement file R-REC-P.534-6-202109-I!!ZIP-E.zip. These maps are based on a global data set containing long-term measurements from 101 ionosonde stations. The latitude grid is from 90°N to 90°S in 1.5° steps, and the longitude grid is from 0°E to 360°E in 1.5° steps.

5 Sporadic-E prediction based on annual-statistics maps

This method gives sporadic-E basic transmission loss not exceeded for a given percentage of an average year based on maps of foEs exceeded for 0.1%, 1%, 10% and 50% of an average year. It is intended primarily for computer implementation where a smooth variation of predicted loss with location is required, primarily to predict interference on long paths for low and mid-latitudes. The method should not be considered reliable at low or high geomagnetic latitudes.

The calculation includes terminal shielding, which varies according to take-off angle. Thus for all path lengths the calculation is made for both 1 hop and 2 hops. These two results are combined at the end of the procedure.

Where information is not available on a terminal horizon elevation angle and distance, an estimate should be used. If the terrain in the area is concerned is known to smooth or include large areas of water, it is possible for surface reflections to contribute to ionospheric propagation, with a consequent reduction in losses. The following method does not attempt to estimate this effect.

5.1 Derivation of foEs

For a given p% time, set the percentage-time values used for interpolation or extrapolation. p_1 and p_2, according to Table 1.

TABLE 1

Conditions for setting p_1 and p_2

p% time	p_1	p_2
$p < 1\%$	0.1%	1%
$1\% \leq p \leq 10\%$	1%	10%
$10\% < p$	10%	50%

For a given location, obtain f_{oEs1} and f_{oEs2} from the maps of f_{oEs} exceeded for p_1 and p_2% time respectively. Calculate f_{oEs} exceeded for p% time using:

$$f_{oEs} = f_{oEs1} + \left(f_{oEs2} - f_{oEs1}\right) \cdot \log\left(p / p_1\right) / \log\left(p_2 / p_1\right) \qquad \text{(MHz)} \qquad (7)$$

5.2 Horizon elevation angles

Additional attenuation can be caused by terrain obstruction at either terminal.

For each terminals, find the terrain point along the great-circle path from the terminal towards the other terminal with the highest elevation angle above the local horizontal as viewed from the terminal. The elevation angle of a given terrain point is given by:

$$\varepsilon_p = \arctan\left(\frac{h_p - h_a}{1000 d_p} - \frac{d_p}{2R_0}\right) \qquad \text{(radians)} \qquad (8)$$

where:

d_p: distance to terrain point, km

h_p : height of terrain point, m above sea level

h_a : height of terminal antenna, m above sea level.

Perform this calculation twice, once for each terminal, to obtain the following:

$\varepsilon_{ha,b}$: elevation angle to horizon at 1st, 2nd terminal, radians;

$d_{ha,b}$: distance to horizon at 1st, 2nd terminal, km.

5.3 Calculation for 1-hop propagation

Obtain f_{oEs} as calculated by equation (7) for the mid-point of the path to obtain the ionospheric loss for one hop, Γ_1, using equation (3).

Calculate the slope path length:

$$l_1 = 2\left\{R_0^{\,2} + (R_0 + h)^2 - 2R_0(R_0 + h)\cos(d/(2R_0))\right\}^{0.5} \qquad \text{(km)} \qquad (9)$$

Free-space loss can now be calculated for the slope distance:

$$L_{bfs1} = 32.4 + 20\log(l_1 \cdot f) \qquad \text{(dB)} \qquad (10)$$

The ray take-off angle above the local horizontal at both terminals for 1 hop is given by:

$$\varepsilon_{r1} = 0.5\pi - \arctan\left\{\frac{R_0\sin(\alpha_1)}{h + R_0[1 - \cos(\alpha_1)]}\right\} - \alpha_1 \qquad \text{(radians)} \qquad (11)$$

where:

$$\alpha_1 = d/(2R_0) \qquad \text{(radians)} \qquad (11a)$$

The diffraction angles, in radians, for the two terminals are given by:

$$\delta_{1a,b} = \varepsilon_{ha,b} - \varepsilon_{r1} \qquad \text{(radians)} \qquad (12)$$

The corresponding diffraction parameters are given by:

$$\nu_{1a,b} = 3.651\sqrt{f\,d_{ha,b}\left[1 - \cos\left(\delta_{1a,b}\right)\right]/\cos\left(\varepsilon_{ha,b}\right)} \qquad \text{if } \delta_{1a,b} \geq 0 \qquad (13a)$$

$$= -3.651\sqrt{f\,d_{ha,b}\left[1 - \cos\left(\delta_{1a,b}\right)\right]/\cos\left(\varepsilon_{ha,b}\right)} \qquad \text{otherwise} \qquad (13b)$$

The diffraction losses in dB at the two terminals are then given by:

$$L_{p1a,b} = 6.9 + 20\log\left[\sqrt{(\nu_{1a,b} - 0.1)^2 + 1} + \nu_{1a,b} - 0.1\right] \qquad \text{if } \nu_{1a,b} > -0.78 \qquad (14a)$$

$$= 0.0 \qquad \text{otherwise} \qquad (14b)$$

Sporadic-E 1-hop basic transmission loss is now given by:

$$L_{bEs1} = L_{bfs1} + \Gamma_1 + L_{p1a} + L_{p1b} \qquad \text{(dB)} \qquad (15)$$

5.4 Calculation for 2-hop propagation

Obtain f_{oEs} as the lower of the two values calculated by equation (7) at one-quarter and three-quarters along the path to re-calculate Γ_1 using equation (3) and thus obtain the ionospheric loss for two hops, Γ_2, using equation (4).

Calculate the slope path length:

$$l_2 = 4\left\{R_0^{\,2} + (R_0 + h)^2 - 2R_0(R_0 + h)\cos(d/(4R_0))\right\}^{0.5} \qquad \text{(km)} \qquad (16)$$

Free-space loss can now be calculated for the slope distance:

$$L_{bfs2} = 32.4 + 20\log(l_2 \cdot f) \qquad \text{(dB)} \qquad (17)$$

The ray take-off angle above the local horizontal at both terminals for 2 hops is given by:

$$\varepsilon_{r2} = 0.5\pi - \arctan\left\{\frac{R_0\sin(\alpha_1)}{h + R_0[1 - \cos(\alpha_1)]}\right\} - \alpha_2 \qquad \text{(radians)} \qquad (18)$$

where:

$$\alpha_2 = d/(4R_0) \qquad \text{(radians)} \tag{18a}$$

The diffraction angles, in radians, for the two terminals are given by:

$$\delta_{2a,b} = \varepsilon_{p2a,b} - \varepsilon_{r2} \qquad \text{(radians)} \tag{19}$$

The corresponding diffraction parameters are given by:

$$\nu_{2a,b} = 3.651\sqrt{f\,d_{ha,b}\left[1-\cos\left(\delta_{2a,b}\right)\right]/\cos\left(\varepsilon_{ha,b}\right)} \qquad \text{if } \delta_{2a,b} \geq 0 \tag{20a}$$

$$= -3.651\sqrt{f\,d_{ha,b}\left[1-\cos\left(\delta_{2a,b}\right)\right]/\cos\left(\varepsilon_{ha,b}\right)} \qquad \text{otherwise} \tag{20b}$$

The diffraction losses in dB at the two terminals are then given by:

$$L_{p2a,b} = 6.9 + 20\log\left[\sqrt{\left(\nu_{2a,b} - 0.1\right)^2 + 1} + \nu_{2a,b} - 0.1\right] \qquad \text{if } \nu_{2a,b} > -0.78 \tag{21a}$$

$$= 0.0 \qquad \text{otherwise} \tag{21b}$$

Sporadic-E 2-hop basic transmission loss is now given by:

$$L_{bEs2} = L_{bfs2} + \Gamma_2 + L_{p2a} + L_{p2b} \qquad \text{(dB)} \tag{22}$$

5.5 Basic transmission loss

Basic sporadic-E transmission loss, L_b (dB) is now given by:

$$L_{bEs} = L_{bEs1} \qquad L_{bEs1} < L_{bEs2} - 20 \tag{23a}$$

$$= L_{bEs2} \qquad L_{bEs2} < L_{bEs1} - 20 \tag{23b}$$

$$= -10 \cdot \log\left(10^{-0.1 \cdot L_{bEs1}} + 10^{-0.1 \cdot L_{bEs2}}\right) \qquad \text{otherwise} \tag{23c}$$
