

RECOMMENDATION ITU-R P.1147-3

**Prediction of sky-wave field strength at frequencies
between about 150 and 1 700 kHz**

(Question ITU-R 225/3)

(1995-1999-2003-2005)

The ITU Radiocommunication Assembly,

considering

- a) that there is a need to give guidance to engineers in the planning of broadcast services in the LF and MF bands;
- b) that it is important, for stations working in the same or adjacent frequency channels, to determine the minimum geographical separation required to avoid interference resulting from long-distance ionospheric propagation;
- c) that portions of this frequency range are being shared by broadcasting and other services in different Regions, an accurate method for predicting interference levels is needed to maintain efficient and orderly utilization of those portions of the spectrum,

recommends

that the following method be adopted for use, taking particular note of the discussion on accuracy given in Annex 1.

1 Introduction

This method predicts values of the night-time sky-wave field strength for a given power radiated from one or more vertical antennas, when measured by a loop antenna at ground level aligned in a vertical plane along the great-circle path to the transmitter. The method has been based on measurements made in the frequency bands allocated to broadcasting and applies for paths of length 50 to 12 000 km for those LF and MF bands in particular. For a discussion on daytime propagation, see Annex 2.

Figures 1, 2 and 3 are an essential part of the prediction method. Geomagnetic maps are included for convenience in Figs. 5, 6 and 10. The remaining Figures and Appendix 1 provide additional information to simplify the use of the method.

2 Annual median night-time field strength

The predicted sky-wave field strength is given by:

$$E = V + E_0 - L_t = V + G_S - L_p + A - 20 \log p - L_a - L_t - L_r \quad (1)$$

where:

E : annual median of half-hourly median field strengths (dB(μ V/m)) for a given transmitter electromotive force, V , and at a given time, t , relative to sunset or sunrise as appropriate

E_0 : annual median of half-hourly median field strengths (dB(μ V/m)) for a transmitter electromotive force of 300 V at the reference time defined in § 2.1

- V : transmitter cymomotive force (dB above a reference cymomotive force of 300 V) (see § 2.2)
- G_S : sea-gain correction (dB) (see § 2.3)
- L_p : excess polarization-coupling loss (dB) (see § 2.4)
- A : a constant. At LF, $A = 110.2$. At MF, $A = 107$ except for propagation paths whose midpoints are situated in the part of Region 3 south of parallel 11° S. In those cases, $A = 110$
- L_a : loss factor incorporating effects of ionospheric absorption and related factors (see § 2.6)
- L_t : hourly loss factor (dB) (see § 2.7)
- L_r : loss factor incorporating effect of solar activity (§ 2.8).

Figure 4 shows E_0 as a function of ground distance, d , for various geomagnetic latitudes when G_S , L_p and R are all zero; where R is the twelve-month smoothed international relative sunspot number.

2.1 Reference time

The reference time is taken as six hours after the time at which the Sun sets at a point S on the surface of the Earth. For paths shorter than 2000 km, S is the mid-point of the path. On longer paths, S is 750 km from the terminal where the Sun sets last, measured along the great-circle path.

2.2 Cymomotive force

The transmitter cymomotive force V (dB(300 V)) is given as:

$$V = P + G_V + G_H \quad (2)$$

where:

- P : radiated power (dB(1 kW))
- G_V : transmitting antenna gain factor (dB) due to vertical directivity, given in Fig. 1
- G_H : transmitting antenna gain factor (dB) due to horizontal directivity. For directional antennas, G_H is a function of azimuth. For omnidirectional antennas, $G_H = 0$.

2.3 Sea gain

The sea gain G_S is the additional signal gain when one or both terminals is situated near the sea, but it does not apply to propagation over fresh water. G_S for a single terminal is given by:

$$G_S = G_0 - c_1 - c_2 \quad \text{for} \quad (c_1 + c_2) < G_0 \quad (3)$$

$$G_S = 0 \quad \text{for} \quad (c_1 + c_2) \geq G_0 \quad (4)$$

where:

- G_0 : sea gain when the terminal is on the coast and the path is unobstructed by further land (dB)
- c_1 : correction to take account of the distance between the terminal and the sea
- c_2 : correction to take account of the width of one or more sea channels, or the presence of islands.

If both terminals are near the sea, G_S is the sum of the values for the individual terminals.

G_0 is given in Fig. 2 as a function of d for LF and MF. At MF, $G_0 = 10$ dB when $d > 6\,500$ km; and at LF $G_0 = 4.1$ dB when $d > 5\,000$ km, where d is the ground distance between the two terminals.

The correction c_1 is given by:

$$c_1 = \frac{s_1}{r_1} G_0 \quad (5)$$

where:

s_1 : distance of terminal from sea, measured along great-circle path (km)

$$r_1 = 10^3 G_0^2 / Q_1 f \quad \text{km}$$

f : frequency (kHz)

$Q_1 = 0.30$ at LF and 1.4 at MF.

The correction c_2 is given by:

$$c_2 = \alpha G_0 \left(1 - \frac{s_2}{r_2} \right) \quad \text{for} \quad s_2 < r_2 \quad (6)$$

$$c_2 = 0 \quad \text{for} \quad s_2 \geq r_2 \quad (7)$$

where:

s_2 : distance of terminal from next section of land, measured along the great-circle path (km)

$$r_2 = 10^3 G_0^2 / Q_2 f \quad \text{km}$$

$Q_2 = 0.25$ at LF and 1.2 at MF

α : proportion of land in the section of path between r_2 and s_2 ($0 < \alpha \leq 1$).

If a computer is used but a terrain data bank is not available to calculate α , then α should be made equal to 0.5, which implies that land and sea are present in equal proportions in the section of path between r_2 and s_2 .

To facilitate calculation, Fig. 8a shows r_1 , the greatest distance from the sea for which sea gain has to be calculated, and Fig. 8b shows r_2 , the greatest distance to the next section of land for which the correction c_2 is required, for various frequencies.

2.4 Polarization coupling loss

L_p is the excess polarization coupling loss (dB). At LF, $L_p = 0$. At MF, L_p for a single terminal is given by one of the following two formulae:

$$L_p = 180 (36 + \theta^2 + I^2)^{-1/2} - 2 \quad \text{dB} \quad \text{for} \quad I \leq 45^\circ \quad (8)$$

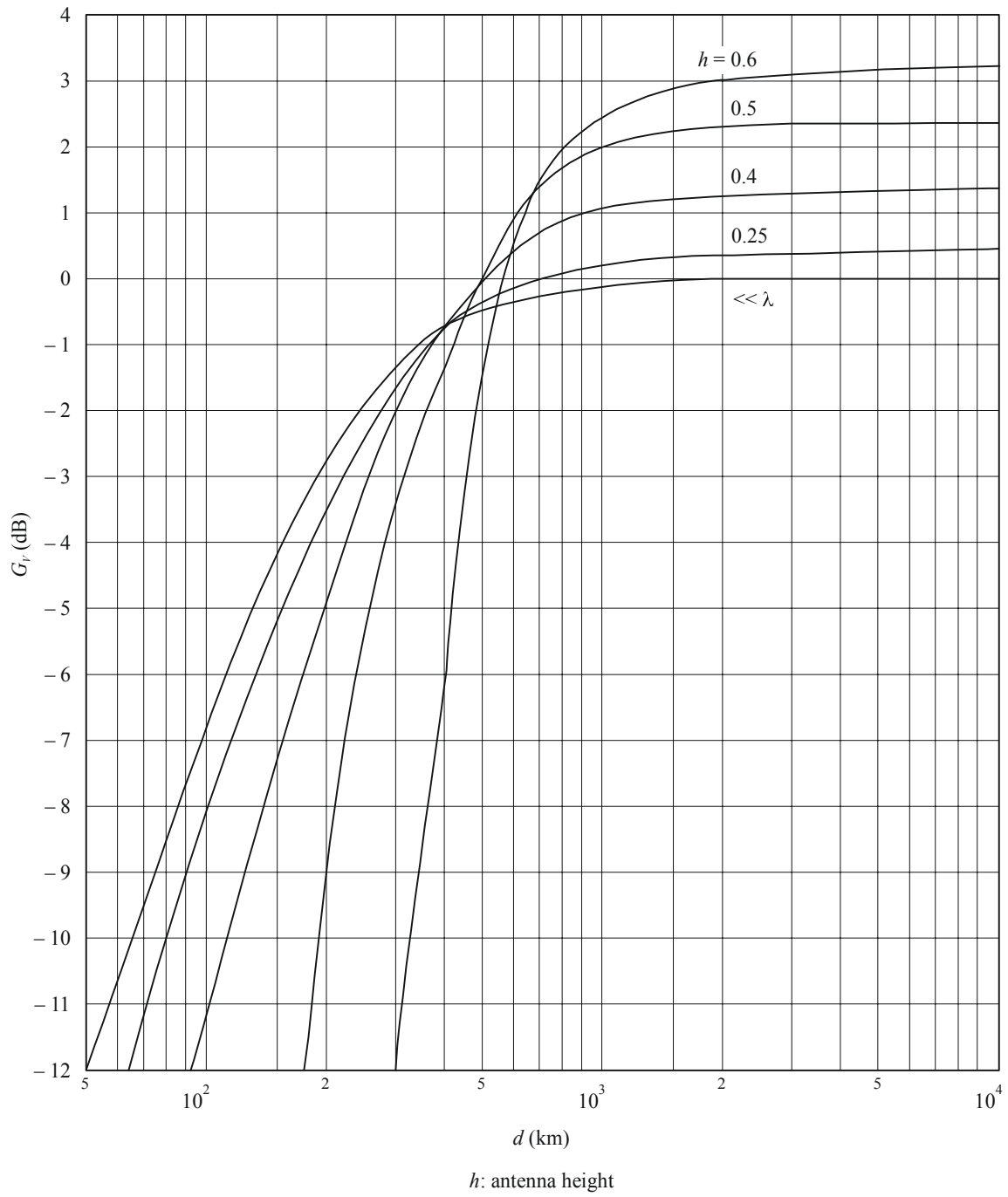
$$L_p = 0 \quad \text{for} \quad I > 45^\circ$$

where I is the magnetic dip, N or S (degrees) at the terminal and θ is the path azimuth measured in degrees from the magnetic E-W direction, such that $|\theta| \leq 90^\circ$. L_p should be evaluated separately for the two terminals, because of the different values of θ and I that may apply, and the two L_p values added. The most accurate available values of magnetic dip and declination (e.g. see Figs. 5 and 6) should be used in determining θ and I .

Figure 7 shows values of L_p calculated from equation (8).

FIGURE 1

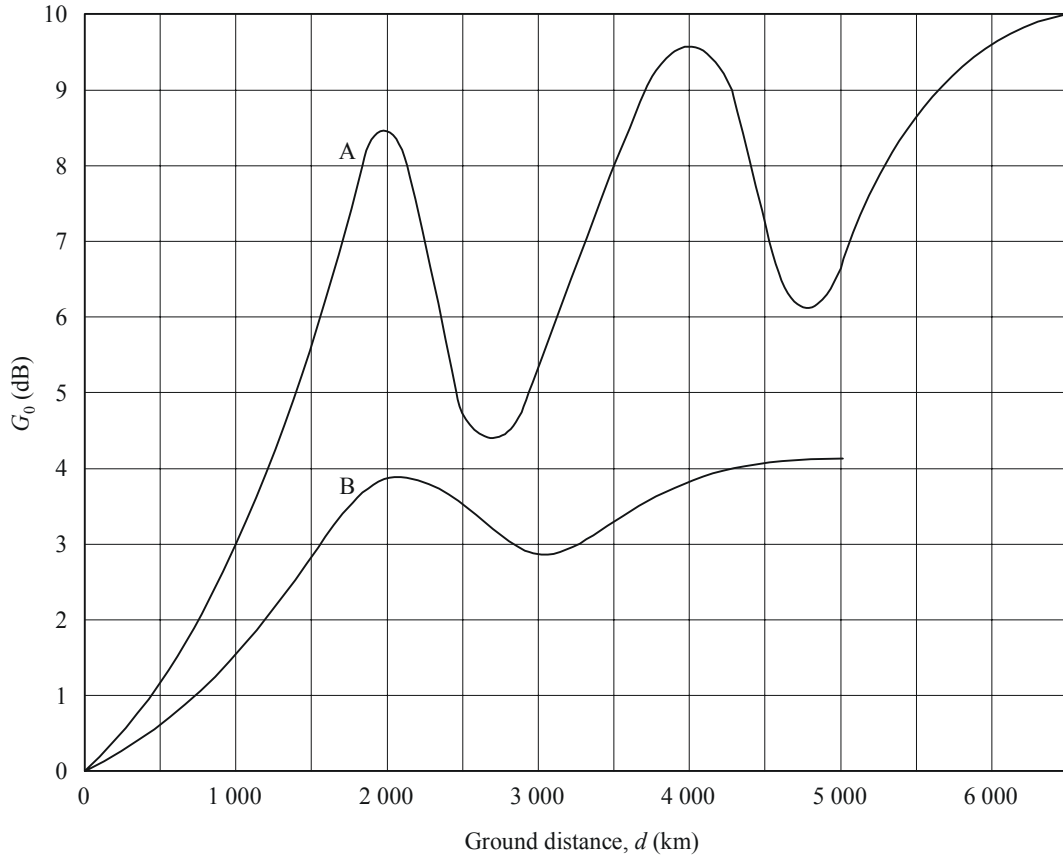
Transmitting antenna gain factor for single monopoles (G_v) over perfect Earth



Note 1 – For $10\,000\text{ km} < d < 12\,000\text{ km}$, readings at $d = 10\,000\text{ km}$ are to be used.

FIGURE 2

Sea gain (G_0) for a single terminal on the coast

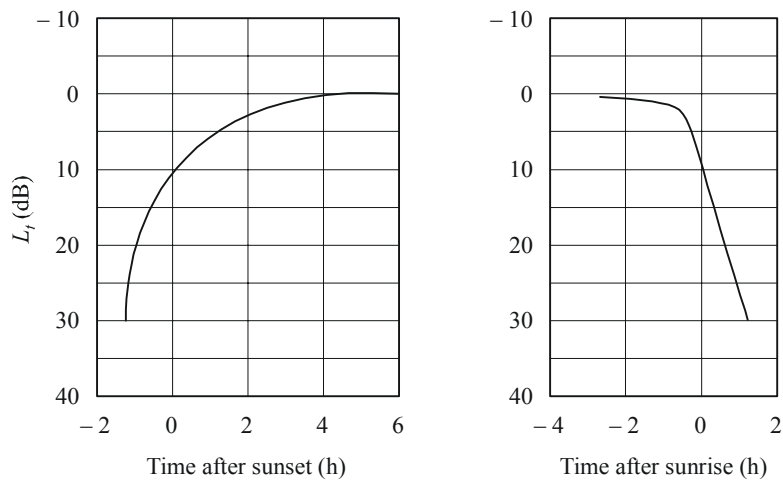


Curves A: MF band
B: LF band

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FIGURE 3

Hourly loss factor (L_f)



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2.5 Slant propagation distance, p

For paths longer than 1 000 km, p (km) is approximately equal to the ground distance, d (km) between transmitter and receiver. For shorter paths:

$$p = (d^2 + 40\,000)^{1/2} \quad (9)$$

Equation (9) may be used for paths of any length with negligible error. It should be used in all cases where the distances considered are both above and below 1 000 km, to avoid discontinuities in field strength as a function of distance.

2.6 Loss factor incorporating effects of ionospheric absorption and related factors

L_a is the loss factor incorporating effects of ionospheric absorption, focusing, terminal losses and loss between hops of multi-hop paths.

$$L_a = k \sqrt{p/1\,000} \quad (10)$$

and the basic loss coefficient k is given by:

$$k = (2\pi + 4.95 \tan^2 \Phi) \quad (11)$$

In equation (11) Φ is the (dipole) geomagnetic latitude of the mid-point of the path under study. Northern latitudes are considered positive, southern latitudes negative. Figure 10 may be used to obtain the geomagnetic latitude from known geographical coordinates of the mid-point. If the value of Φ is greater than $+60^\circ$, equation (11) is evaluated for $\Phi = +60^\circ$. If the value of Φ is less than -60° , equation (11) is evaluated for $\Phi = -60^\circ$. Paths longer than 3 000 km are divided into two equal sections, k for each section is determined according to equation (11). The algebraic average of the two values of k (k_{eff}) is then used in calculating field strength (see also Fig. 9).

2.7 Hourly loss factor

The hourly loss factor, L_t (dB) is given in Fig. 3. The time t is the time in hours relative to the sunrise or sunset time as appropriate. This time is taken at the ground at the mid-path position for paths where $d < 2\,000$ km. For paths longer than 2 000 km, the times are determined at points 750 km from each terminal, and the selected time is the one where the solar elevation angle is higher. The large values of hourly loss factor near midday are not defined (Fig. 3). For times in this period use a limit value of 30 dB. The hourly loss factor should not be calculated for high latitude paths and seasons when sunrise and sunset do not occur.

Equations generally equivalent to these curves to within 0.5 dB are given in § 1 of Appendix 1. Figure 3 represents the average annual diurnal variation.

Figure 11 shows sunset and sunrise times for a range of geographic latitudes and months. Equations equivalent to these sunset and sunrise curves are given in § 2 of Appendix 1.

2.8 Loss factor incorporating effect of solar activity

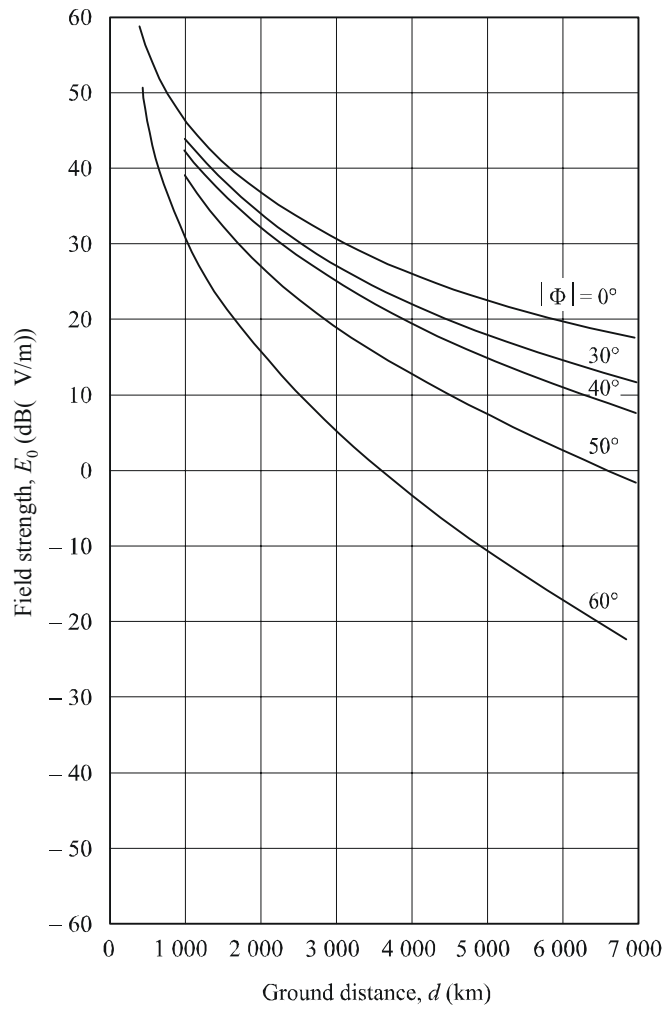
L_r is the loss factor incorporating effect of solar activity and is given by the following formulae:

$$\begin{array}{ll} \text{at LF,} & L_r = 0 \\ \text{at MF,} & \text{if } |\Phi| \leq 45^\circ, \quad L_r = 0 \\ \text{at MF,} & \text{if } |\Phi| > 45^\circ, \quad L_r = b(R/100) (p/1\,000) \quad \text{dB} \end{array} \quad (12)$$

where:

$$b = (|\Phi| - 45)/3 \quad \text{except in Europe where } b = 1 \text{ is to be used regardless of latitude.} \quad (13)$$

Paths longer than 3 000 km are divided into two equal sections as described in § 2.6. The value of L_r for each section is derived and added together.



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3 Day-to-day and short-period variations of night-time field strengths

The difference, $\Delta(w)$, where w is typically 10 or 1, at a specific time relative to sunset or sunrise, between the field strength exceeded for w % of the time and the annual median value is given by:

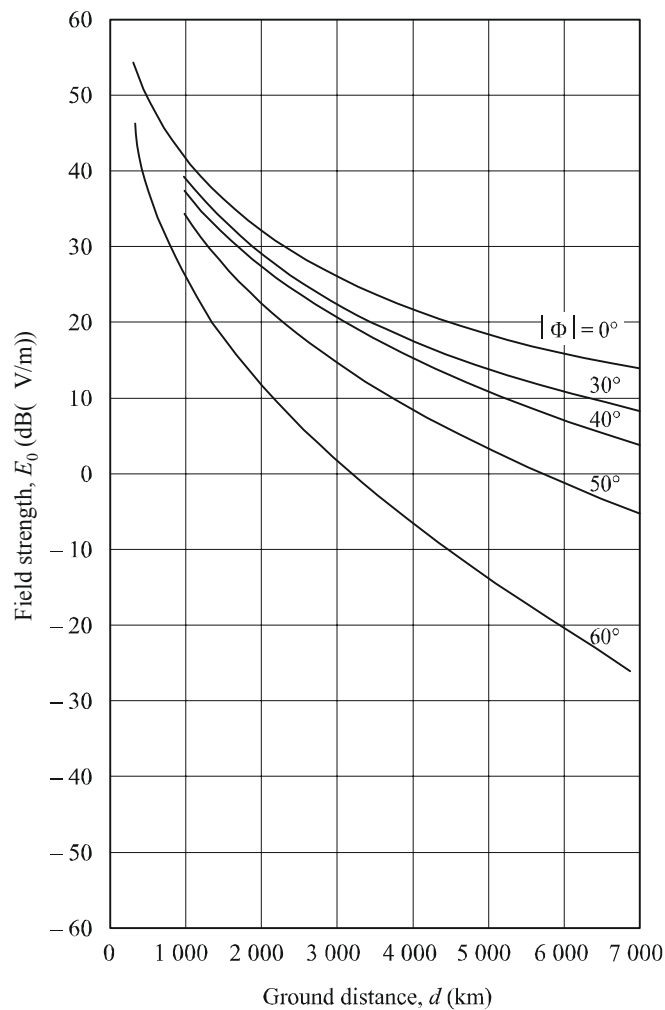
$$\text{at LF:} \quad \Delta(10) = 6.5 \quad \text{dB} \quad (14)$$

$$\text{and} \quad \Delta(1) = 11.5 \quad \text{dB} \quad (15)$$

$$\text{at MF:} \quad \Delta(10) = 0.2 |\Phi| - 2 \quad \text{dB} \quad (16)$$

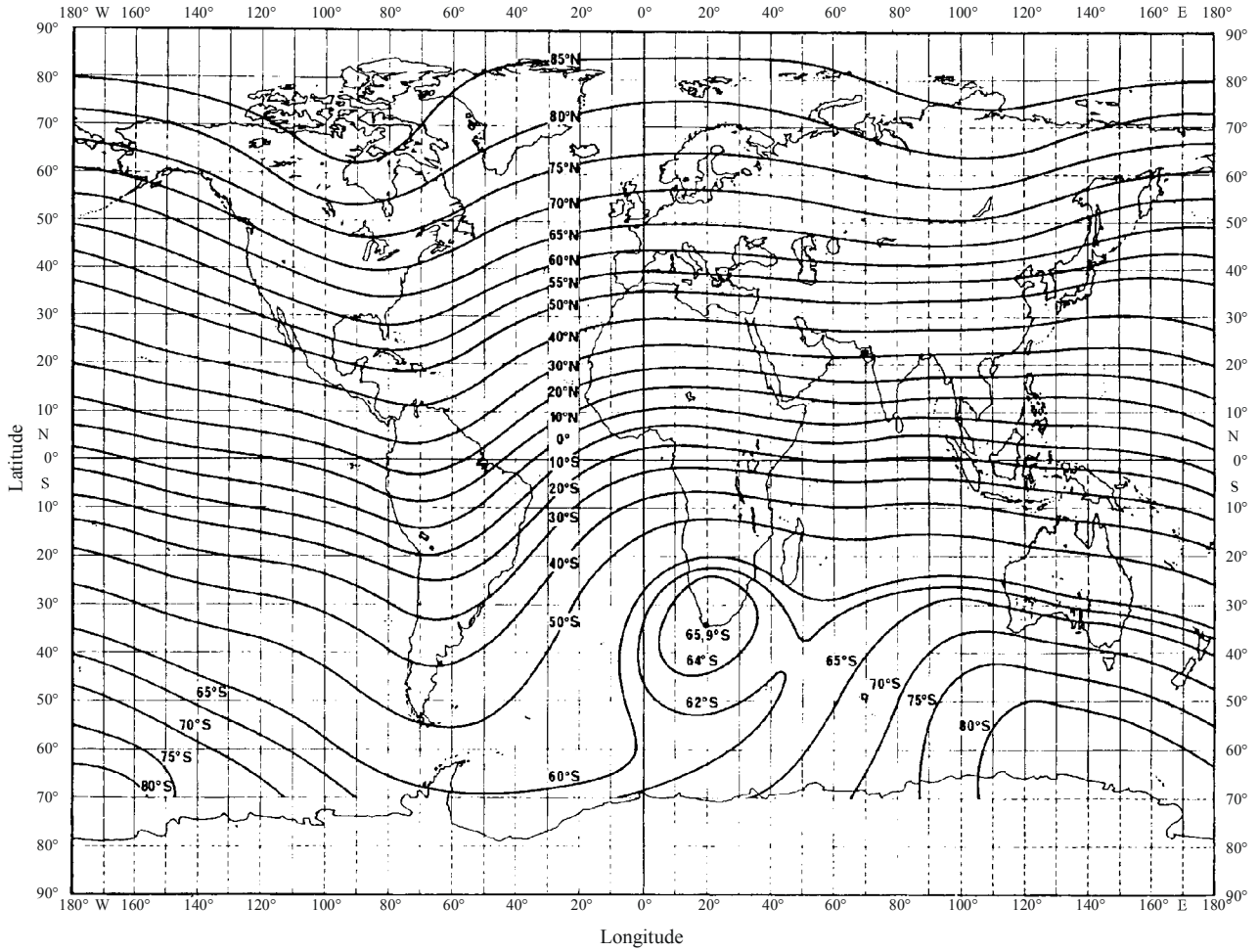
$$\text{and} \quad \Delta(1) = 0.2 |\Phi| + 3 \quad \text{dB} \quad (17)$$

In equation (16), $\Delta(10)$ is greater than or equal to 6 dB but less than or equal to 10 dB. In equation (17), $\Delta(1)$ is greater than or equal to 11 dB but less than or equal to 15 dB.



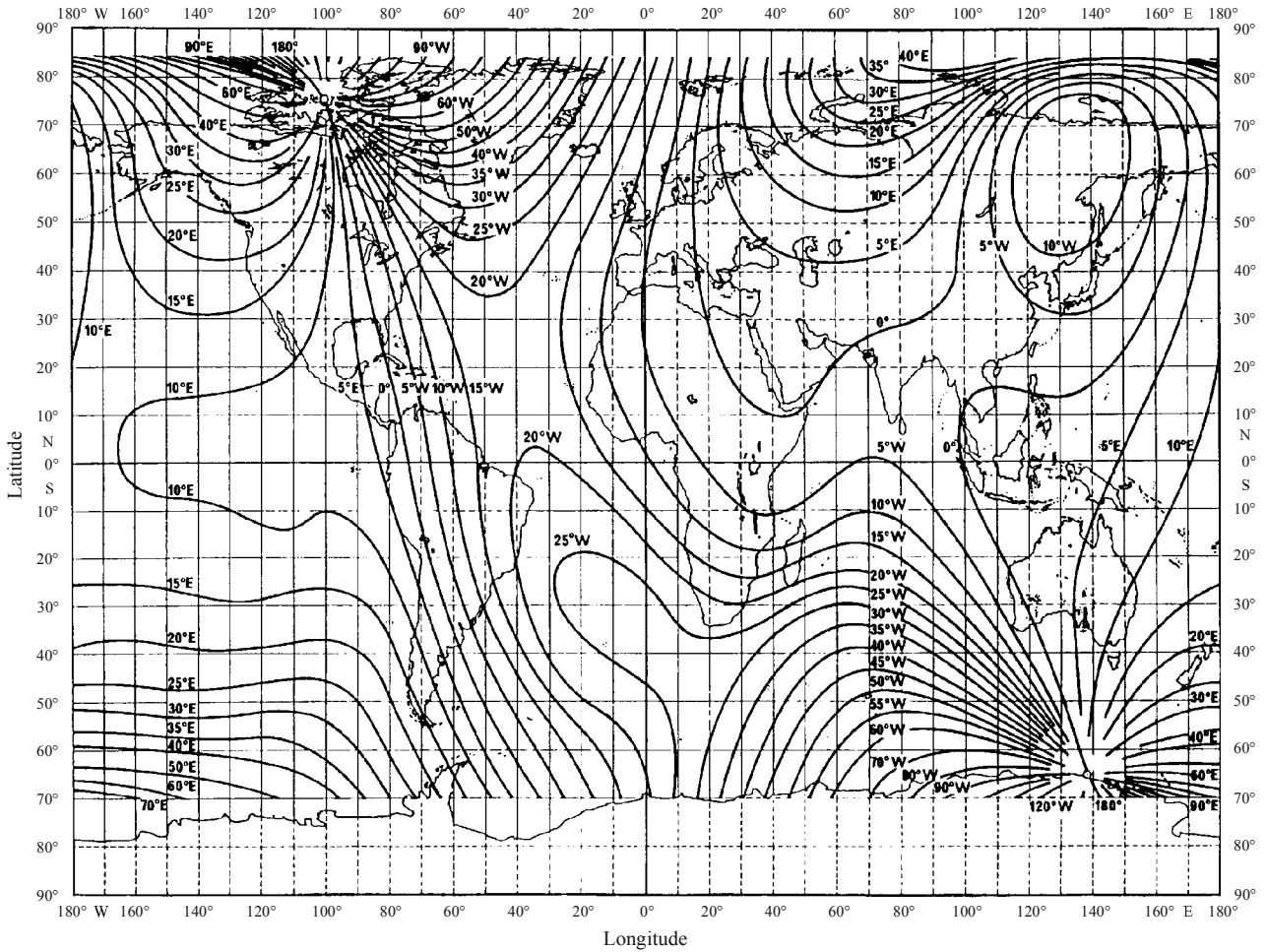
Note 1 – For applications in Southern Region 3, add 3 dB.

FIGURE 5
Map of magnetic dip (epoch 1975.0)



(Source: Magnetic inclination or dip (epoch 1975.0) Chart No. 30 World U.S. Defense Mapping Agency Hydrographic Center)

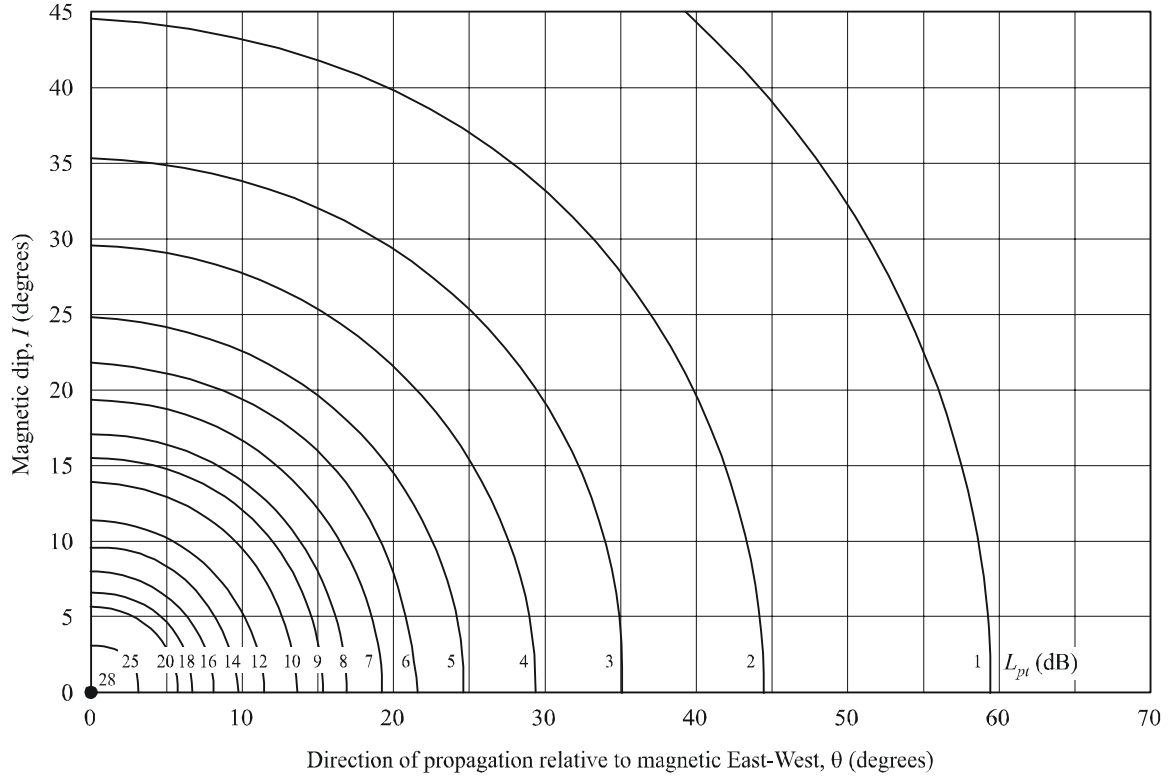
FIGURE 6
Map of magnetic declination (epoch 1975.0)



(Source: Magnetic variation (epoch 1975.0) Chart No. 42 World U.S. Defence Mapping Agency Hydrographic Center)

FIGURE 7

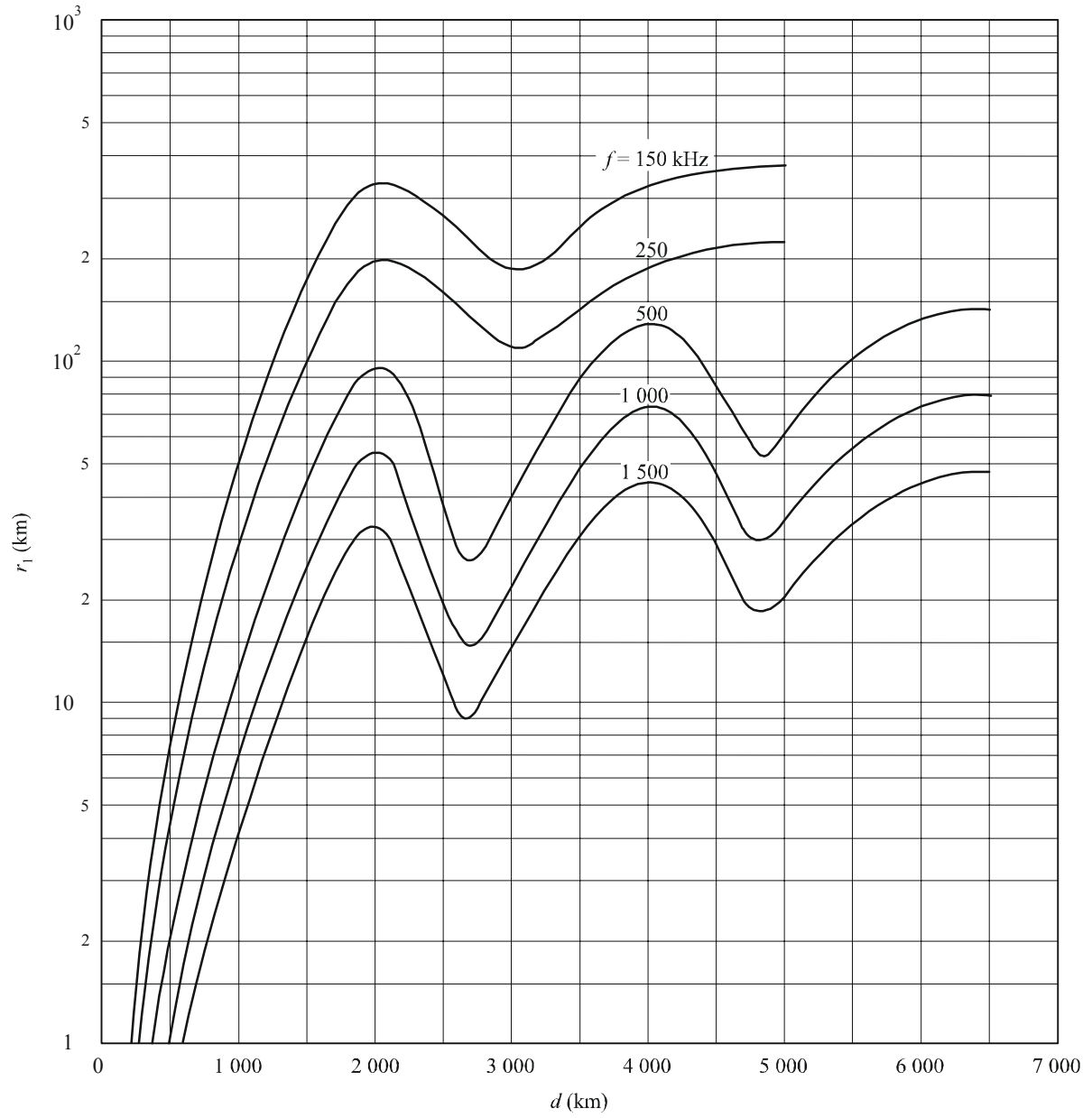
Excess polarization coupling loss L_p (for a single terminal)



$$L_p = 180 (36 + \theta^2 + I^2)^{-1/2} - 2$$

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FIGURE 8a

Values of r_1 for various frequencies

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FIGURE 8b
Values of r_2 for various frequencies

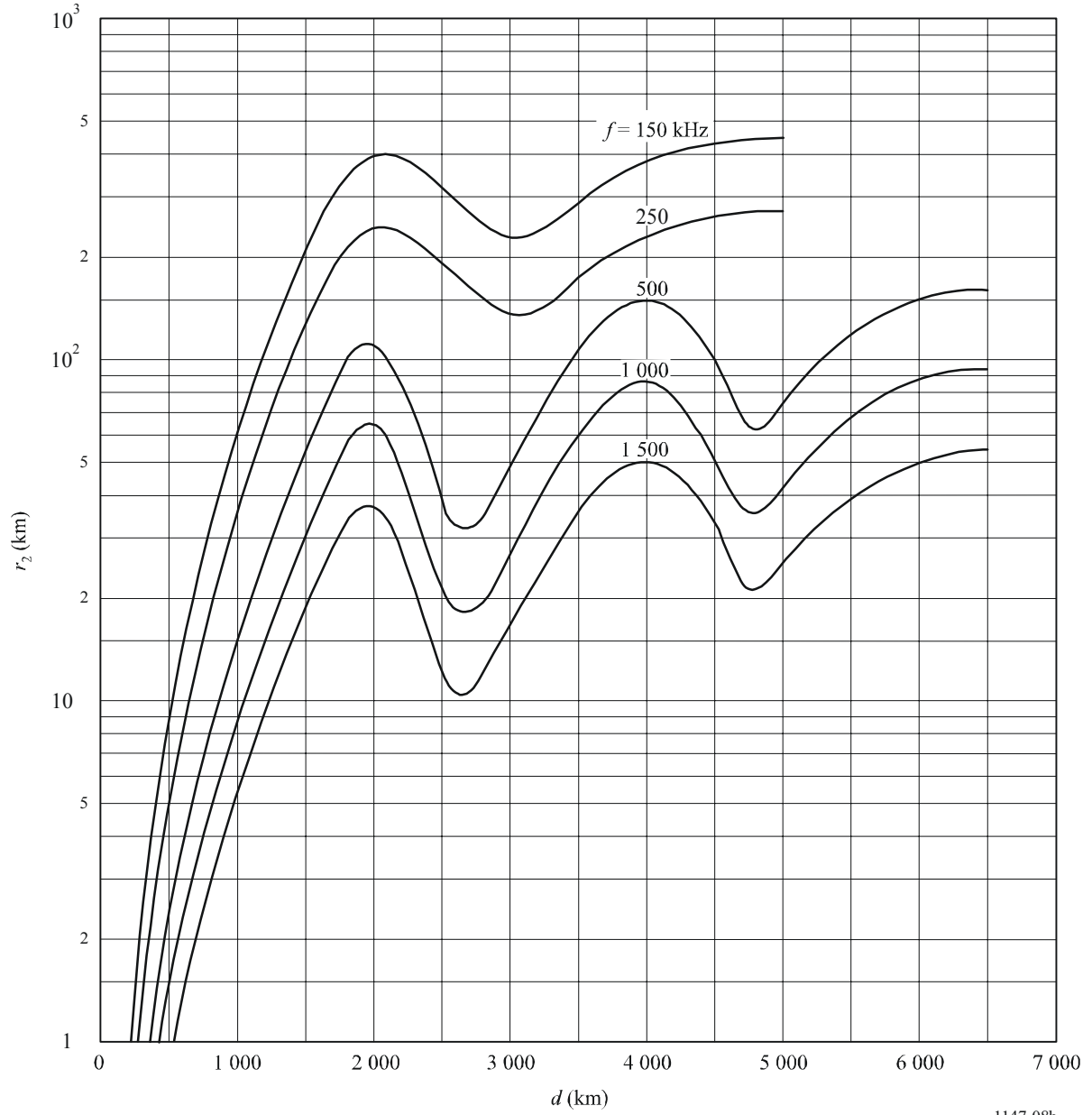
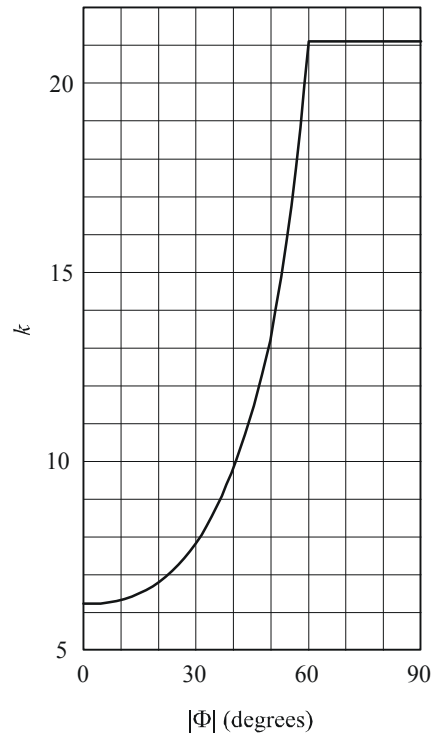


FIGURE 9
Basic loss coefficient



$$k = (2 + 4.95 \tan^2 \Phi) \quad \text{for } \Phi \leq 60^\circ$$

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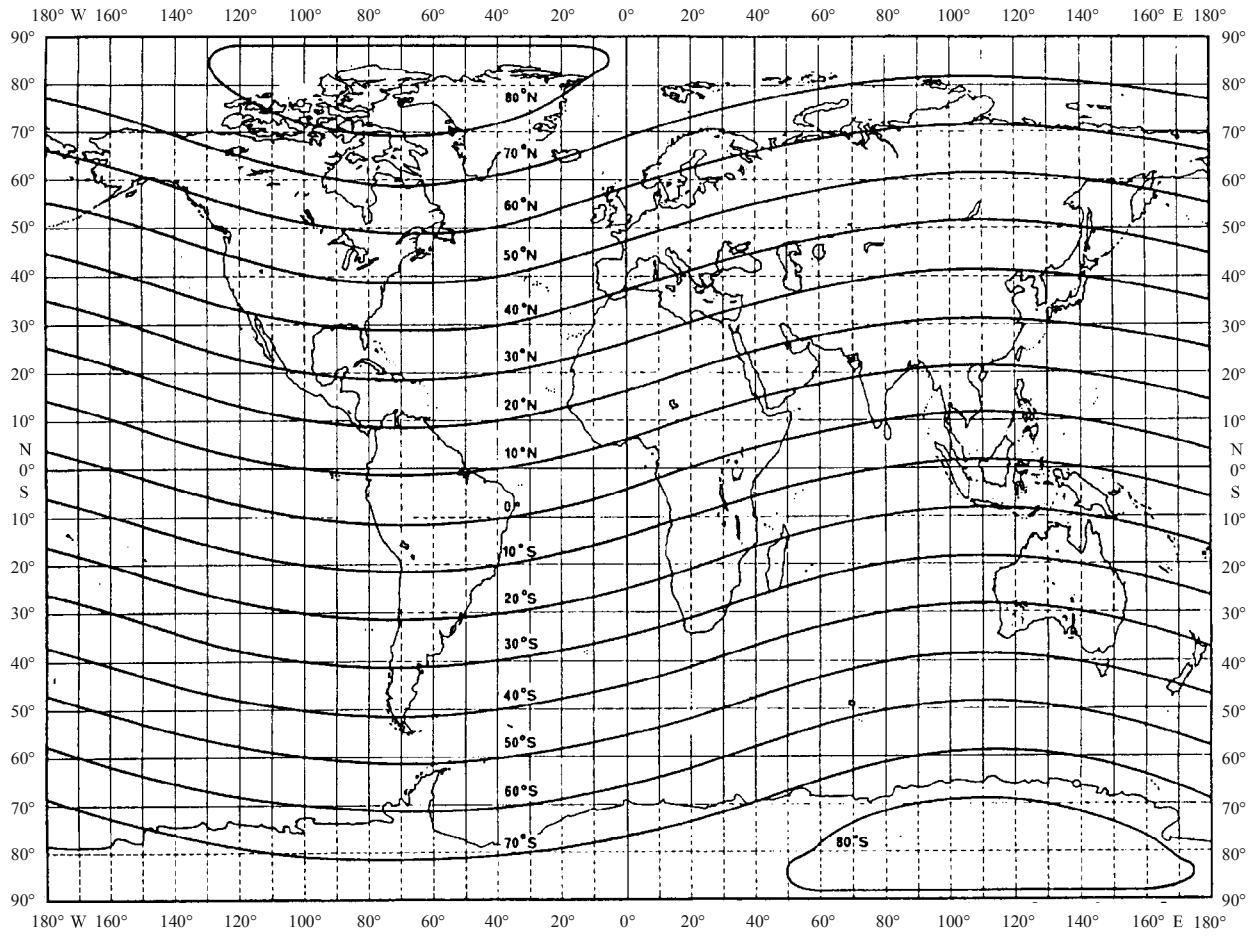
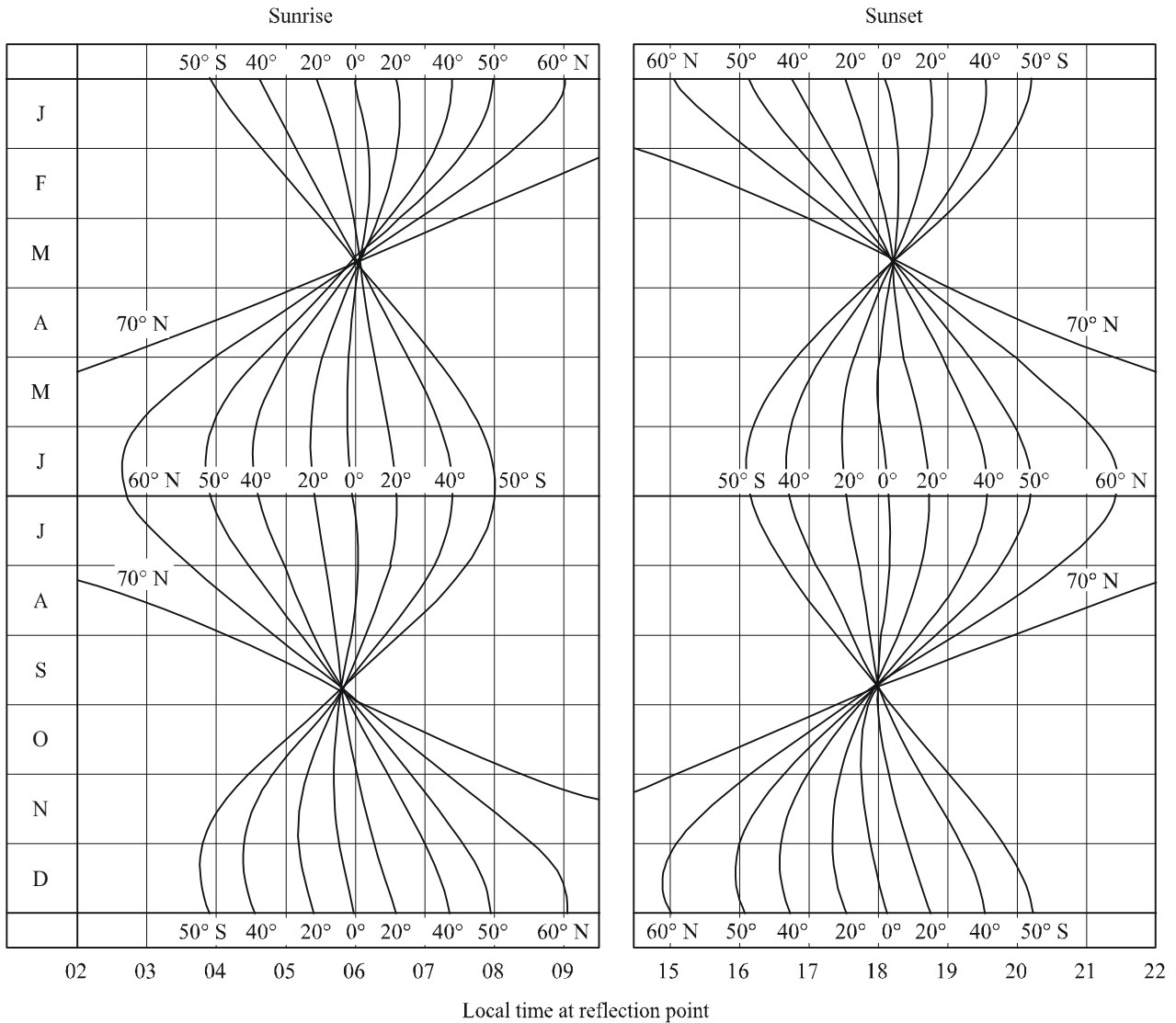


FIGURE 11
Times of sunrise and sunset for various months and geographical latitudes



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Appendix 1

This Appendix contains equations that may be used in lieu of Figs. 3 and 11 for hourly loss factor, and sunset and sunrise times respectively. For the purpose of this Appendix, the following additional symbols are used.

List of symbols

- α : geographic latitude of a point on the path (degrees)
- β : geographic longitude of a point on the path (degrees)
- S : local mean time of sunset or sunrise at a point (h).

North and East coordinates are considered positive, and South and West coordinates negative.

1 Hourly loss factor: L_t

These equations may be used instead of the curves in Fig. 3, within the stated limits of t . For hours between these times (i.e. near midnight) set $L_t = 0$.

$$L_t \text{ (sunset)} = 12.40 - 9.248 t + 2.892 t^2 - 0.3343 t^3 \quad \text{for } -1 < t \text{ (sunset)} < 4$$

$$L_t \text{ (sunrise)} = 9.6 + 12.2 t + 5.62 t^2 + 0.86 t^3 \quad \text{for } -3 < t \text{ (sunrise)} < 1$$

where t is the time in hours relative to sunset or sunrise at the path mid-point.

2 Sunset and sunrise times

For non-polar locations, i.e. such that $|\alpha| < 65^\circ$, the times of sunset and sunrise can be calculated as follows, to an accuracy of ± 2 min:

N : day of year, in days; e.g. 1 January = 1

S' : approximate local time of event, e.g. sunset = 1800 h, sunrise = 0600 h

Z : Sun's zenith distance (degrees) = $90.8333^\circ(90^\circ 50')$ for sunset or sunrise.

Step 1: Calculate observer's longitude, B :

$$B = \beta / 15 \quad \text{h}$$

Step 2: Calculate the time of event, Y :

$$Y = N + (S' - B) / 24 \quad \text{days}$$

Step 3: Calculate Sun's mean anomaly, M :

$$M = 0.985600 Y - 3.289 \quad \text{degrees}$$

Step 4: Calculate Sun's longitude, L :

$$L = M + 1.916 \sin M + 0.020 \sin 2 M + 282.634 \quad \text{degrees}$$

Note in which quadrant L occurs.

Step 5: Calculate Sun's right ascension, RA :

$$\tan RA = 0.91746 \tan L$$

Note that RA must be in the same quadrant as L .

Step 6: Calculate Sun's declination, s :

$\sin s = 0.39782 \sin L$, from which:

$$\cos s = + \sqrt{1 - \sin^2 s}$$

Note that $\sin s$ may be positive or negative but $\cos s$ must always be positive.

Step 7: Calculate Sun's local hour angle, H :

$$\cos H = x = (\cos Z - \sin s \cdot \sin \alpha) / (\cos s \cdot \cos \alpha)$$

Note that if $|x| > 1$, there is no sunset or sunrise.

From $\cos H$, obtain H in degrees; for sunrise $180 < H < 360$; for sunset $0 < H < 180$.

Step 8: Calculate local mean time of event, S :

$$S = H / 15 + RA / 15 - 0.065710 Y - 6.622$$

Note that S is expressed in hours and that multiples of 24 should be added or subtracted until $0 < S < 24$.

Note that S is the local time at the point concerned. The corresponding standard time is $S - B + \beta_m / 15$ h where β_m is the longitude of the standard meridian for the desired time zone (degrees) so that, for example, universal time = $S - B$.

Annex 1

Accuracy of method

The method applies for paths of length 50 to 12 000 km in the LF and MF bands. However, at LF it has only been verified for paths up to 7 500 km.

The special treatment for the southern part of Region 3 might not have been necessary if “corrected geomagnetic latitude” had been used rather than geomagnetic latitude. In any case, the method should be used with caution for geomagnetic latitudes greater than 60°.

Equation (6) which describes how G_S is modified by the distance s_2 to the next section of land is derived from theory and must therefore be regarded as tentative until measurements are available.

The method predicts the field strength which is likely to be observed if the transmitter and receiver are situated on ground of average conductivity, typically 3 to 10 mS/m. In certain areas (e.g. see Recommendation ITU-R P.832), the effective ground conductivity can be as low as 0.5 mS/m or as high as 40 mS/m. If the ground conductivity at either terminal is an order of magnitude smaller than 10 mS/m, then the field strength may be up to 10 dB smaller. If the ground conductivity at both terminals is an order of magnitude smaller, then the field-strength reduction will be doubled. The amount of attenuation is a function of path length and is greatest for waves approaching grazing incidence. The method may be improved by using a correction for ground conductivity when it differs significantly from that for average ground, for example by using the information contained in the ITU-R Handbook – The ionosphere and its effects on radiowave propagation.

The method assumes that reflection takes place only via the E layer, or that E-layer reflections predominate. However, if $f > (foE) \sec i$, where foE is the critical frequency of the E layer and i is the angle of incidence at the E layer, then the wave will penetrate the E layer and be reflected from the F layer. This is most likely to occur at the highest frequencies in the MF band at ground distances less than 500 km, especially late at night and during the sunspot minimum period. The method can still be used provided p is calculated for an F-layer reflection height of 220 km and the cymomotive force V is calculated for the corresponding angle of elevation.

Measurements made in the United States of America suggest that Fig. 3 (hourly loss factor) is likely to be accurate for frequencies near 1 000 kHz in a year of low solar activity. As the frequency deviates in either direction from about 1 000 kHz, particularly during transition hours, appreciable errors may result. These measurements also suggest that the magnitude of the effect of solar activity at two hours after sunset is considerably greater than that at six hours after sunset. Thus, in a year of high solar activity, the difference between field strengths at six hours after sunset and two hours after sunset can be considerably greater than that shown in Fig. 3.

At night, MF sky-waves propagating in temperate latitudes are strongest in spring and autumn and are weakest in summer and winter, the summer minimum being the more pronounced. The overall variation may be as much as 15 dB at the lowest frequencies in the MF band, decreasing to about 3 dB at the upper end of the band. At LF the seasonal variation at night has the opposite trend, with a pronounced summer maximum. The seasonal variation is much smaller in tropical latitudes.

Annex 2

A discussion on daytime sky-wave propagation

1 LF cases

Midday field strengths at LF are 7 to 45 dB lower than the values at midnight. The difference is dependent on frequency, distance and season (see also Recommendation ITU-R P.684).

2 MF cases

Available data show that midday sky-wave field strengths display a consistent seasonal variation pattern with maximum occurring in winter months. The average winter-month field strength is about 10 dB stronger than the annual median value and the winter-to-summer ratio can exceed 30 dB. The annual median value of midday field strength is about 43 dB lower than its counterpart at six hours after sunset. Field strength exceeded for 10% of the days of the year is about 13 dB stronger than the annual median value. See also the ITU-R Handbook – The ionosphere and its effects on radiowave propagation.
