RECOMMENDATION 683*

SKY-WAVE FIELD STRENGTH PREDICTION METHOD FOR PROPAGATION TO AIRCRAFT AT ABOUT 500 kHz

(Study Programme 31D/6)

(1990)

The CCIR,

CONSIDERING

(a) that Question 53-2/8, which concerns the use of frequencies by the maritime mobile service, in the bands 435-526.5 kHz, asks *inter alia* what are the sharing criteria with other services, taking into consideration the propagation mechanisms for a receiving antenna located well above the ground level;

(b) that a method for sky-wave field strength prediction for receivers close to the ground is given in Recommendation 435; and that information on the accuracy of that method is given in § 6 of Annex I of that Recommendation,

UNANIMOUSLY RECOMMENDS

that the method described in Annex I should be used for the prediction of sky-wave field strength at about 500 kHz in the vicinity of high flying aircraft.

ANNEX I

1. Introduction

This method of prediction gives the night-time sky-wave field strength at the position occupied by an aircraft when a given power is radiated from a short vertical antenna at 500 kHz. It applies for paths up to 4000 km and should be used with caution for geomagnetic latitudes greater than 60°.

The sky-wave field at the aircraft will in general be elliptically polarized. Aircraft antennas may respond differently to vertical and horizontal fields, and the combined effect of these fields may depend on the size of the aircraft and on its heading relative to the direction of arrival of the sky wave. Additionally, the down-coming sky wave will be reflected by the ground and the field at the aircraft will thus depend also on the reflection coefficient and angle of arrival of the down-coming wave. Furthermore, the location of the reflection point will change rapidly as the aircraft moves. Additionally, there may be significant differences between predicted field strengths and measured data for low angles of arrival.

The prediction method therefore gives only the maximum vertical and horizontal field components which would be measured in the vicinity of the aircraft after taking local ground reflections into account.

Formulae for the strength of the down-coming sky wave are given in § 2 and formulae for the maximum values of the vertical and horizontal electric field components in the vicinity of the aircraft are given in § 3.

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[*] This Recommendation is brought to the attention of Study Group 8.

2. Field strength of down-coming sky wave

The down-coming sky wave is in general elliptically polarized. The power flux-density of the down-coming wave can be represented by an equivalent field strength given by:

$$E_D = V + G_S + G_0 - L_{pt} + A_0 - 20 \log p - 10^{-3} k_R p - L_t \qquad (1)$$

where:

E_D : annual median of half-hourly median field strengths (dB(μV/m)) for a given transmitter cymomotive force, V, and at a given time, t, relative to sunset or sunrise as appropriate, for the down-coming wave,

V : transmitter cymomotive force, dB above a reference cymomotive force of 300 V (see § 2.2),

G_S : sea-gain correction at the transmitter (dB) (see § 2.3),

G_0 : a parameter given in Fig. 1 as a function of d (dB),

L_{pt} : excess polarization-coupling loss at the transmitter (dB) (see § 2.4),

$A_0 =$ 101.6 - 2 sin Φ, where Φ is defined by equation (12),

p : slant-propagation distance (km) (see § 2.5),

k_R : loss factor incorporating effects of ionospheric absorption, focusing and terminal losses, and losses between hops on multi-hop paths (see § 2.6),

L_t : hourly loss factor (dB) (see § 2.7).

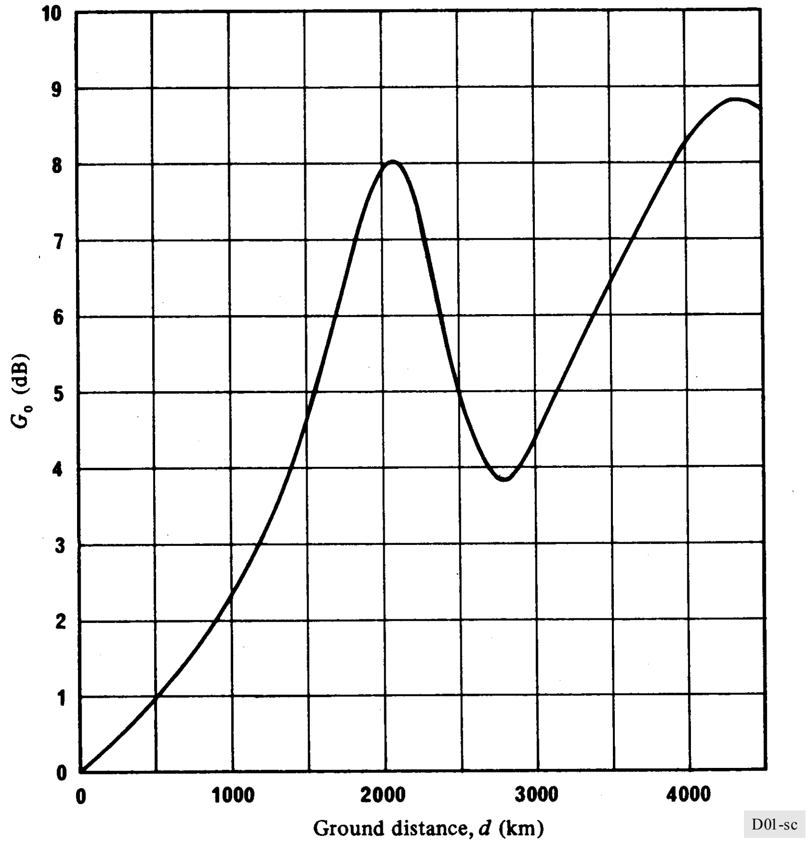

FIGURE 1 – *Sea gain (G_0) for a transmitter on the coast*

Note. – This curve is not the same as curve A of Fig. 2 of Recommendation 435, as it applies to 500 kHz.

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 cymomotive force V is given as:

$$V = P + 20 \log (d / p) \tag{2}$$

where:

P : radiated power (dB(1 kW)),

d : ground distance (km),

p : slant-propagation distance (km).

For paths longer than 1000 km, V is approximately equal to P.

Note. – the reference cymomotive force of 0 dB (300V) corresponds to an e.m.r.p. of 1 kW.

2.3 *Sea gain*

G_S is the additional signal gain when the transmitter is situated near the sea, but it does not apply to propagation over fresh water. G_S is given by:

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

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

where:

G_0 : gain when the transmitter is on the coast and the sea is unobstructed by further land,

c_1 : correction to take account of the distance between the transmitter and the sea,

c_2 : correction to take account of the width of one or more sea channels, or the presence of islands.

G_0 is given in Fig. 1 as a function of d.

The correction c_1 is given by

$$c_1 = \frac{s_1}{r_1} G_0 \tag{5}$$

where:

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

$r_1 = 1.4 \, G_0^2$ (km).

The correction c_2 is given by:

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

$$c_2 = 0 \qquad \text{for} \quad s_2 \geq r_2 \tag{7}$$

where:

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

$r_2 = 1.7 \, G_0^2$ (km).

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. 2 shows r_1, the greatest distance from the sea for which sea gain has to be calculated, and also shows r_2, the greatest distance to the next section of land for which the correction c_2 is required.

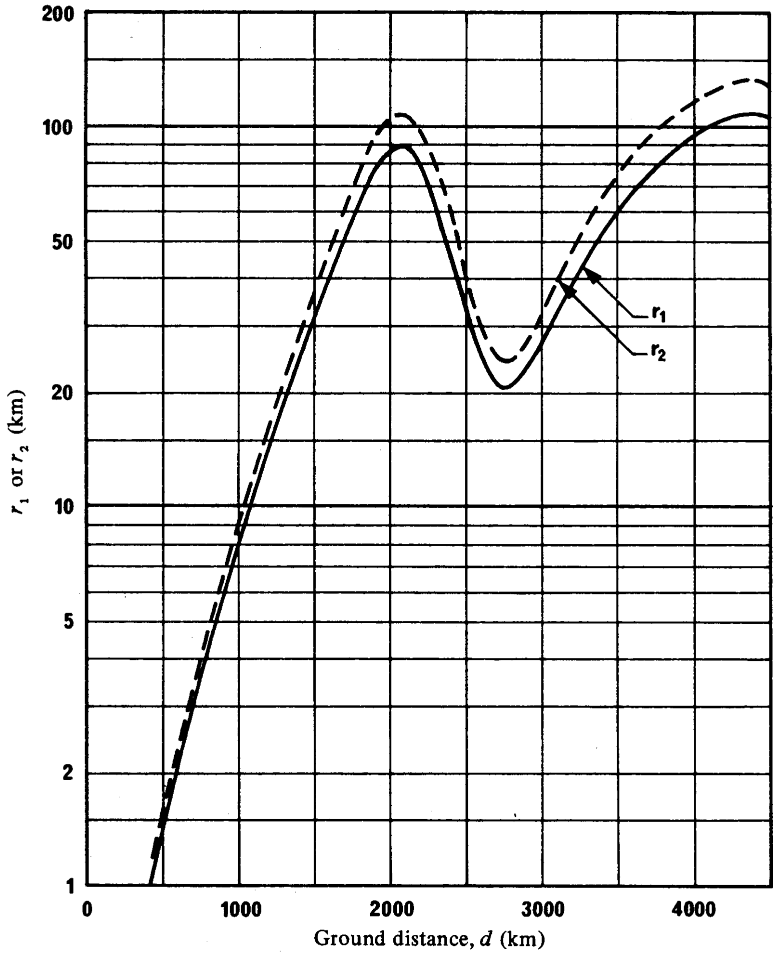

FIGURE 2 – *Values of* r_1 *and* r_2

2.4 *Polarization coupling loss at transmitter,* L_{pt}

L_{pt} is the excess polarization coupling loss, given by one of the following two formulae:

$$L_{pt} = 180\,(36 + \theta^2 + I^2)^{-1/2} - 2 \qquad \text{dB} \quad \text{if } I \leq 45°$$

$$L_{pt} = 0 \qquad \text{if } I > 45° \tag{8}$$

where I is the magnetic dip, North or South, in degrees at the transmitter and θ is the path azimuth measured in degrees from the magnetic East-West direction, such that $|\ \theta\ | \leq 90°$. The most accurate available values of magnetic dip and declination (e.g. see Figs. 11 and 12 of Recommendation 435) should be used in determining θ and I.

Figure 3 shows values of L_{pt} calculated from equation (8).

2.5 *Slant propagation distance*

For paths longer than 1000 km, p is approximately equal to the ground distance d (km). For shorter paths

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

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 1000 km, to avoid discontinuities in field strength as a function of distance.

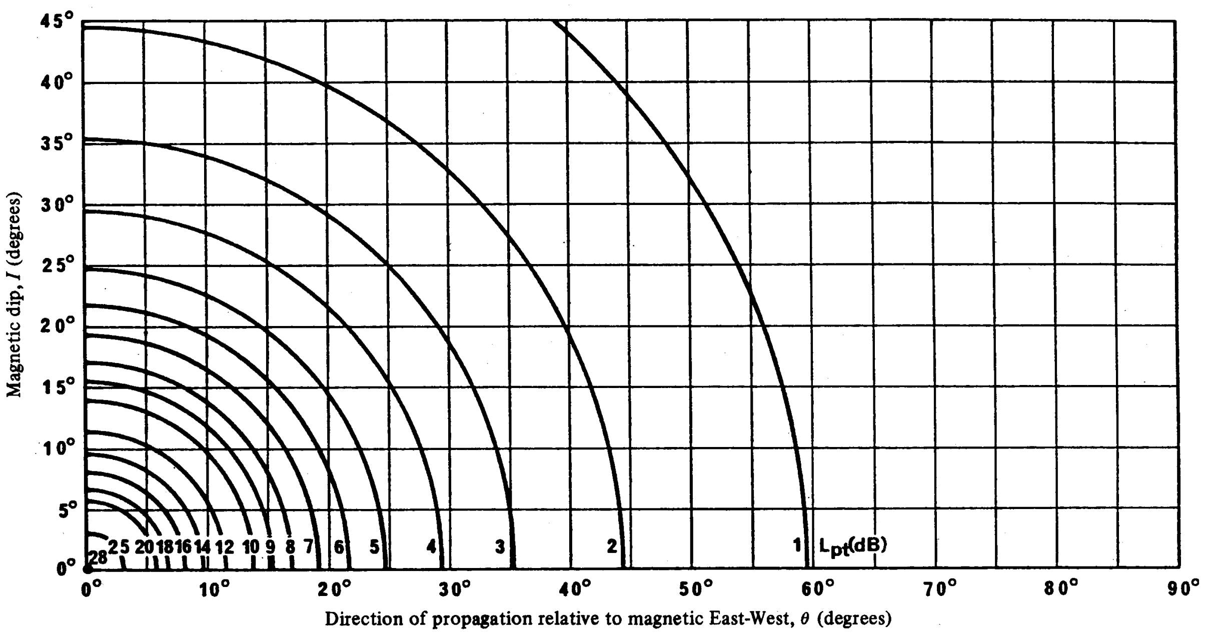

FIGURE 3 – *Excess polarization coupling loss* L_{pt}

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

2.6 *Loss factor*

The loss factor k_R is given by

$$k_R = k + 10^{-2}\, b\, R \tag{10}$$

where:

R : twelve-month smoothed International Relative Sunspot Number and

$b = 4$ for North American paths,

$b = 1$ for Europe and Australia and

$b = 0$ elsewhere.

The basic loss factor k is given by:

$$k = 3.2 + 2.28 \tan^2 (\Phi + 3) \tag{11}$$

If $\Phi > 60°$, equation (11) is evaluated for $\Phi = 60°$. If $\Phi < -60°$, equation (11) is evaluated for $\Phi = -60°$. Figure 15 of Recommendation 435 (curve for 500 kHz) shows values of k calculated from equation (11) according to these rules.

For paths shorter than 3000 km:

$$\Phi = 0.5\,(\Phi_T + \Phi_R) \tag{12}$$

where Φ_T and Φ_R are the geomagnetic latitudes at the transmitter and receiver respectively, determined by assuming an Earth-centred dipole field model with northern pole at 78.5° N, 69° W geographic co-ordinates. Φ_T and Φ_R are taken as positive in the northern hemisphere and negative in the southern hemisphere (see Fig. 16 of Recommendation 435). Paths longer than 3000 km are divided into two equal sections which are considered separately. The value of Φ for each half-path is derived by taking the average of the geomagnetic latitudes at one terminal and at the mid-point of the whole path, the geomagnetic latitude at the mid-point of the whole path being assumed to be the average of Φ_T and Φ_R. As a consequence:

$$\Phi = 0.25\,(3\Phi_T + \Phi_R) \qquad \text{for the first half of the path and} \tag{13}$$

$$\Phi = 0.25\,(\Phi_T + 3\Phi_R) \qquad \text{for the second half} \tag{14}$$

The values of k calculated from equation (11) for the two half-paths are then averaged and used in equation (10).

2.7 *Hourly loss factor*

The hourly loss factor, L_t, is given in Fig. 3 of Recommendation 435 which shows the average of the annual median hourly variations for Europe and Australia, derived from Figs. 2 and 6 of Report 431 respectively. The time, t, is the time in hours relative to the sunrise or sunset reference times as appropriate. These are taken at the ground at the mid-path position for $d < 2000$ km and at 750 km from the terminal where the Sun sets last or rises first for longer paths.

Figure 17 of Recommendation 435 shows sunset and sunrise times for a range of geographic latitudes.

3. Field strength in the vicinity of the aircraft

The down-coming sky wave will be reflected by the ground and the resultant field strength in the vicinity of the aircraft will be the vector sum of the down-coming sky wave and the ground reflected wave. The field strength will be greatest when the two waves add in phase. The resultant field strength is assumed to be 6 dB greater than that of the down-coming wave because in-phase addition is always possible.

The resultant electric field may be resolved into a transverse horizontal component E_{HT} and a component which lies in the vertical plane. The latter component, which is not itself vertical, can in turn be resolved into a vertical component E_V and a longitudinal horizontal component E_{HL}.

It should be noted that the total field may also contain a ground wave: e.g. for aircraft flying at a height of about 11 km, the ground wave is receivable to distances up to 400 km. However, no account is taken of the ground wave in this prediction method.

3.1 *Vertical component*

The maximum vertical electric field strength E_V at the aircraft is given by:

$$E_V = E_D - L_{pv} + 5 + 20 \log (d / p) \tag{15}$$

where:

L_{pv} : excess polarization coupling loss at receiver, for vertical polarization.

L_{pv} is given by equation (8) by writing L_{pv} in place of L_{pt}. The values of θ and I which apply at the position of the aircraft should be used.

3.2 *Transverse horizontal component*

The maximum transverse horizontal electric field strength E_{HT} at the aircraft is given by:

$$E_{HT} = E_D - L_{ph} + 6 \tag{16}$$

where:

L_{ph} : excess polarization coupling loss for horizontal polarization.

L_{ph} is given by Fig. 4. Values derived from Fig. 4 for temperate latitudes should be used with caution for paths shorter than 500 km.

3.3 *Longitudinal horizontal component*

The maximum longitudinal horizontal electric field strength E_{HL} at the aircraft is given by:

$$E_{HL} = E_D - L_{pv} + 51 - 20 \log p \tag{17}$$

E_{HL} can be disregarded for paths longer than 1000 km.

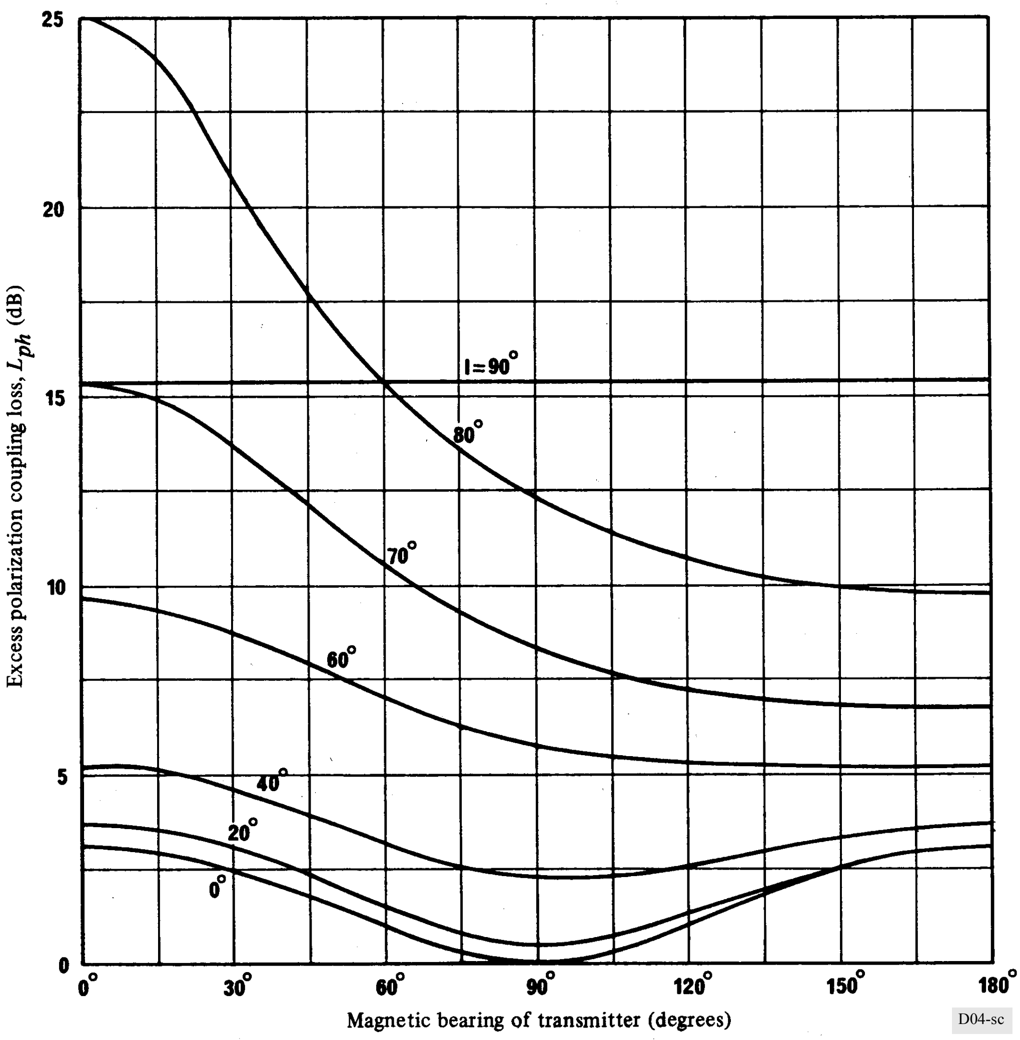

FIGURE 4 – *Excess polarization coupling loss L_{ph} for horizontal polarization*

I: magnetic dip angle, North or South (degrees)

Note. – If the aircraft is North of the magnetic dip equator, the magnetic bearing of the transmitter is measured from magnetic North. If the aircraft is South of the dip equator, the bearing is measured from magnetic South.

4. Field-strength variation

The field strength exceeded for 10% of the total time on a series of nights at a given season, during short periods centred on a specific time, is 8 dB greater than the value of E_D given in § 2. Larger values may be observed at the peak of the solar cycle.

At night, 500 kHz 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. The seasonal variation is much smaller in tropical latitudes.

5. Day-time field strength

In Europe the median day-time field strength in winter is 25 dB less than the night-time value of E_D given in § 2. In summer the day-time field strength is about 60 dB less than E_D.

In spring and autumn in Europe, day-time field strengths have values between the summer and winter values.