The information contained within Appendix B is taken from CCIR Recommendation 435-3, Sky-wave Field Strength Prediction Method for the Frequency Range 150 to 1600 kHz, published in Volume VI of the Recommendations and Reports of the CCIR, 1978, as passed at the XIVth Plenary Assembly, Kyoto, Japan.

ANNEX I

SKY-WAVE FIELD STRENGTH PREDICTION METHOD
FOR THE FREQUENCY RANGE 150 TO 1600 kHz

List of symbols

A :	A parameter defined in § 2.
b :	Solar-activity factor given in § 2.6.
d :	Ground distance between transmitter and receiver (km).
F :	Annual median field strength for a given cymomotive force (c.m.f.), V, and at a given time t, relative to sunset or sunrise as appropriate.
F_0 :	Annual median field strength at the reference time defined in § 2 (dB(μV/m)).
f :	Frequency (kHz).
f' :	A frequency defined in equation (6) (kHz).
G_0 :	Sea gain for a terminal on the coast (dB).
G_H :	Transmitting antenna gain factor due to horizontal directivity (dB).
G_S :	Sea gain for a terminal near the sea (dB).
G_V :	Transmitting antenna gain factor due to vertical directivity (dB).
h :	Transmitting antenna height (Fig. 1).
h_r :	Height of reflecting layer (km).
I :	Magnetic dip angle, N or S, (degrees).
k :	Basic loss factor.
k_R :	Loss factor.
L_P :	Excess polarisation coupling loss (dB).
L_t :	Hourly loss factor (dB).
P :	Radiated power (dB(1 kW)).
p :	Slant propagation distance (km).
Q_1, Q_2 :	Sea-gain parameters given in § 2.3.
R :	Twelve-month smoothed Zurich sunspot number.
r_1, r_2 :	Parameters defined in § 2.3.
s_1 :	Distance of terminal from sea, measured along great-circle path (km).
s_2 :	Distance of terminal from next section of land, measured along great-circle path (km).
t :	Time relative to sunset or sunrise (hours).
V :	Transmitter cymomotive force (dB(300 V)).
θ :	Direction of propagation relative to magnetic East-West (degrees).
λ :	Wavelength.
Φ :	A geomagnetic latitude parameter.
Φ_T :	Geomagnetic latitude of transmitter } (degrees, positive in northern hemisphere
Φ_R :	Geomagnetic latitude of receiver } negative in southern hemishphere).

1. Introduction

This method of prediction gives the night-time sky-wave field strength produced for a given power radiated from one or more vertical antennae, when measured by a loop antenna at ground level aligned in a vertical plane along the great-circle path to the transmitter. It applies for paths of lengths up to 12 000 km in bands 5 (LF) and 6 (MF). * However, in band 5 it was only verified for paths of up to 5000 km. The accuracy of prediction varies from region to region and may be improved in certain regions by applying modifications such as those shown in § 6. In any case the method should be used with caution for geomagnetic latitudes greater than 60°.

* Band 5 covers the frequency range of about 150 to 285 kHz and band 6 covers the range of about 520 to 1600 kHz.

Figs. 1, 2 and 3 are an essential part of the prediction method. Geomagnetic maps are included for convenience in Figs. 11, 12 and 16. The remaining Figs. 4 to 10, 13 to 15 and 17, 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:

$$F = V + F_0 - L_t = V + G_S - L_P + A - 20 \log p - 10^{-3} k_R \, p - L_t \qquad (1)$$

where,

- F: 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,
- F_0: annual median of half-hourly median field strengths (dB(μV/m)) for a transmitter cymomotive 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: 106.6 – 2 sin Φ, where Φ is defined by equation (9),
- 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).

To facilitate calculation, Fig. 4 shows the quantity $A - 20 \log p$, for $\Phi = 40°$ as a function of ground distance, d, whereas Figs. 5 to 10 show F_0 as a function of ground distance, d, for various frequencies and for various geomagnetic latitudes when G_S, L_P and R are all zero.

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:

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

where,

- P: radiated power, dB above 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 antennae, G_H is a function of azimuth. For omnidirectional antennae, $G_H = 0$.

2.3 *Sea gain*

G_S is the additional signal gain when one or both terminals are situated near the sea. G_S for a single terminal is given by:

$$G_S = \left(\frac{s_2}{r_2} - \frac{s_1}{r_1} \right) G_0 \qquad \text{(dB)} \qquad (3)$$

where,

- G_0: gain when the terminal is on the coast and the sea is unobstructed by further land,
- s_1: distance of terminal from sea, measured along great-circle path (km),
- s_2: distance of terminal from next section of land, measured along great-circle path (km),
- $r_1 = 10^3 \, G_0^2 / Q_1 f$
- $r_2 = 10^3 \, G_0^2 / Q_2 f$
- f: frequency (kHz),
- Q_1 = 0.30 in band 5 and 1.4 in band 6,
- Q_2 = 0.25 in band 5 and 1.2 in band 6.

G_0 is given in Fig. 2 as a function of d for bands 5 and 6. In band 6, $G_0 = 10$ dB when $d > 6500$ km. Equation (3) applies for values of s_1 and s_2 such that $G_S > 0$. For larger values of s_1, $G_S = 0$. If $s_2 > r_2$, G_S is calculated with $s_2 = r_2$. If $s_2 < r_2$ and if more than half the distance between s_2 and a great-circle distance equal to r_2 is occupied by land, equation (3) applies, but if less than half the distance between s_2 and r_2 is occupied by land, G_S is calculated with $s_2 = r_2$.

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

Equation (3) should not be used for fresh water.

2.4 *Polarization coupling loss*

L_P is the excess polarization coupling loss. In band 5, $L_P = 0$. In band 6, L_P for a single terminal is given by one of the following two formulae:

$$\text{If } I \leqslant 45°: L_P = 180\,(36 + \theta^2 + I^2)^{-1/2} - 2 \qquad \text{dB} \tag{4}$$

$$\text{If } I > 45°: L_P = 0$$

where I is the magnetic dip, N or S, in degrees at the terminal and θ is the path azimuth measured in degrees from the magnetic E-W direction, such that $|\theta| \leqslant 90°$. L_P should be evaluated separately for the two terminals, because of the different 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. 11 and 12) should be used in determining θ and I.

Fig. 13 shows values of L_P calculated from equation (4).

2.5 *Slant propagation distance*

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

$$p = (d^2 + 4h_r^2)^{1/2} \tag{5}$$

where $h_r = 100$ km if $f \leqslant f'$ and 220 km if $f > f'$, as shown in Fig. 14 where f' (in kHz) is given by:

$$f' = 350 + [(2.8d)^3 + 300^3]^{1/3} \tag{6}$$

Equation (5) may be used for paths of any length with negligible error.

2.6 *Loss factor*

The loss factor k_R is given by

$$k_R = k + 10^{-2}\,bR \tag{7}$$

where R = twelve-month smoothed Zurich sunspot number. In band 5, $b = 0$. In band 6, $b = 4$ for North American paths, 1 for Europe and Australia and 0 elsewhere.

The basic loss factor k is given by:

$$k = 3.2 + 0.19\,f^{0.4}\tan^2(\Phi + 3) \tag{8}$$

where f = frequency (kHz). If $\Phi > 60°$, equation (8) is evaluated for $\Phi = 60°$. If $\Phi < -60°$, equation (8) is evaluated for $\Phi = -60°$. Fig. 15 shows values of k calculated from equation (8) according to these rules.

For paths shorter than 3000 km:

$$\Phi = 0.5\,(\Phi_T + \Phi_R) \tag{9}$$

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). 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:

$$\Phi = (3\Phi_T + \Phi_R)/4 \text{ for the first half of the path and} \tag{10}$$

$$\Phi = (\Phi_T + 3\Phi_R)/4 \text{ for the second half.} \tag{11}$$

The values of k calculated from equation (8) for the two half-paths are then averaged and used in equation (7).

2.7 *Hourly loss factor*

The hourly loss factor, L_t, is given in Fig. 3, which shows the average of the annual median hourly variations for Europe and Australia, derived from Figs. 2 and 6 of Report 431-2 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.

Fig. 17 shows sunset and sunrise times for a range of geographic latitudes.

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

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

6.5 dB greater in band 5

8 dB greater in band 6

than the value of F_0 given in § 2. Larger values may be observed at the peak of the solar cycle.

4. Seasonal variation of night-time field strength

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.

5. Day-time field strength

In band 5 in Europe the median day-time field strength in winter is 10 dB less than the night-time value of F_0 given in § 2. In summer the daytime field strength is 30 dB less than F_0. The field strength exceeded for 10% of the total time on a series of days in winter, during short periods centred on a specific time, is 5 dB greater than the median day-time value given above.

In band 6 in Europe the median day-time field strength in winter is 25 dB less than the night-time value of F_0 given in § 2. In summer the day-time field strength is about 60 dB less than F_0.

In spring and autumn in Europe, day-time field strengths in bands 5 and 6 have values between the summer and winter values.

6. Accuracy of the method

The accuracy in the United States of America may be improved by using a reference time of two hours after sunset. Field strengths measured in the United States of America tend to be greater at higher frequencies; the frequency variation given by equation (8) is in the opposite sense.

The term in equation (3) 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.

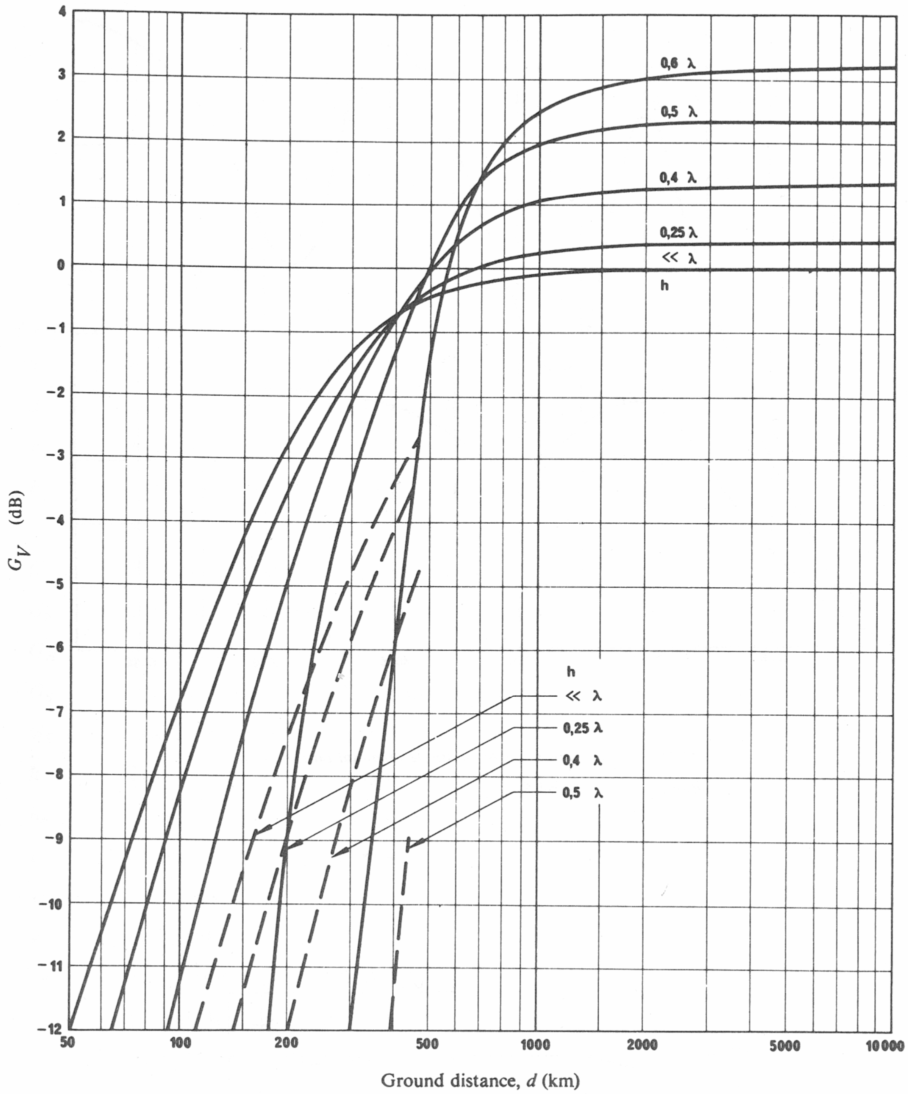

FIGURE 1 – *Transmitting antenna gain factor for monopoles* (G_V)

h = Antenna height

——— h_r = 100 km (E layer reflection)

— — — h_r = 220 km (F layer reflection)

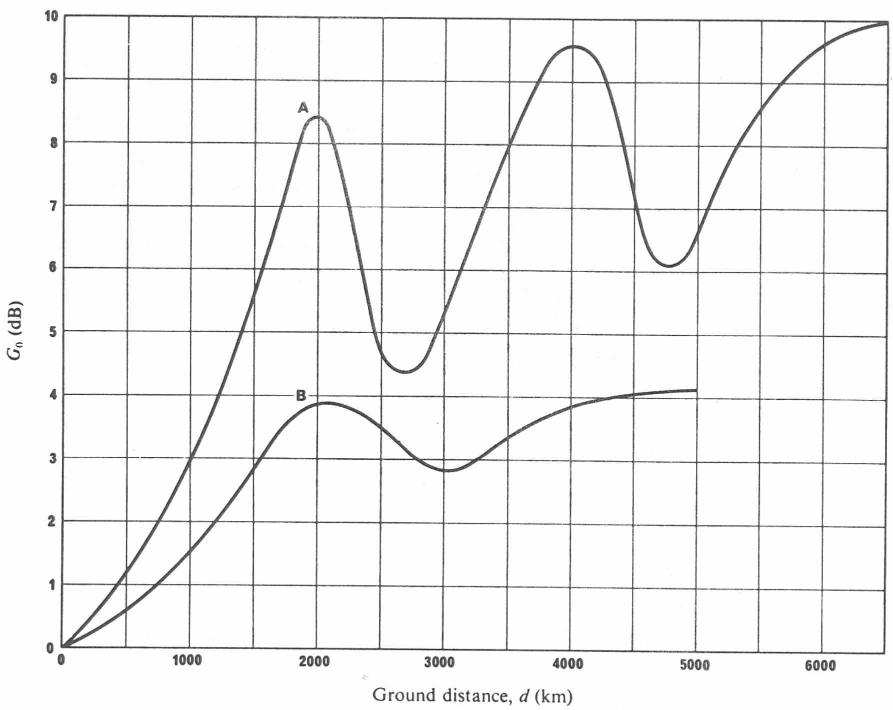

FIGURE 2 – *Sea gain (G_0) for a single terminal on the coast*

A: Band 6 B: Band 5

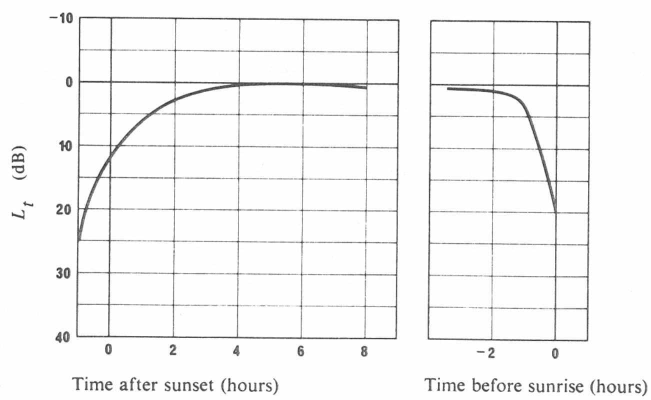

FIGURE 3 – *Hourly loss factor (L_t)*

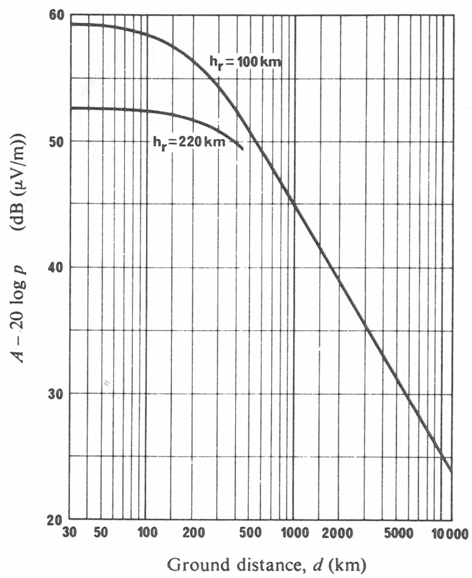

FIGURE 4 – *Basic field strength*

The curves show = $A - 20 \log p$

Where $A = 106.6 - 2 \sin \Phi$
$\Phi = 40°$
$p = (d^2 + 4h_r^2)^{1/2}$

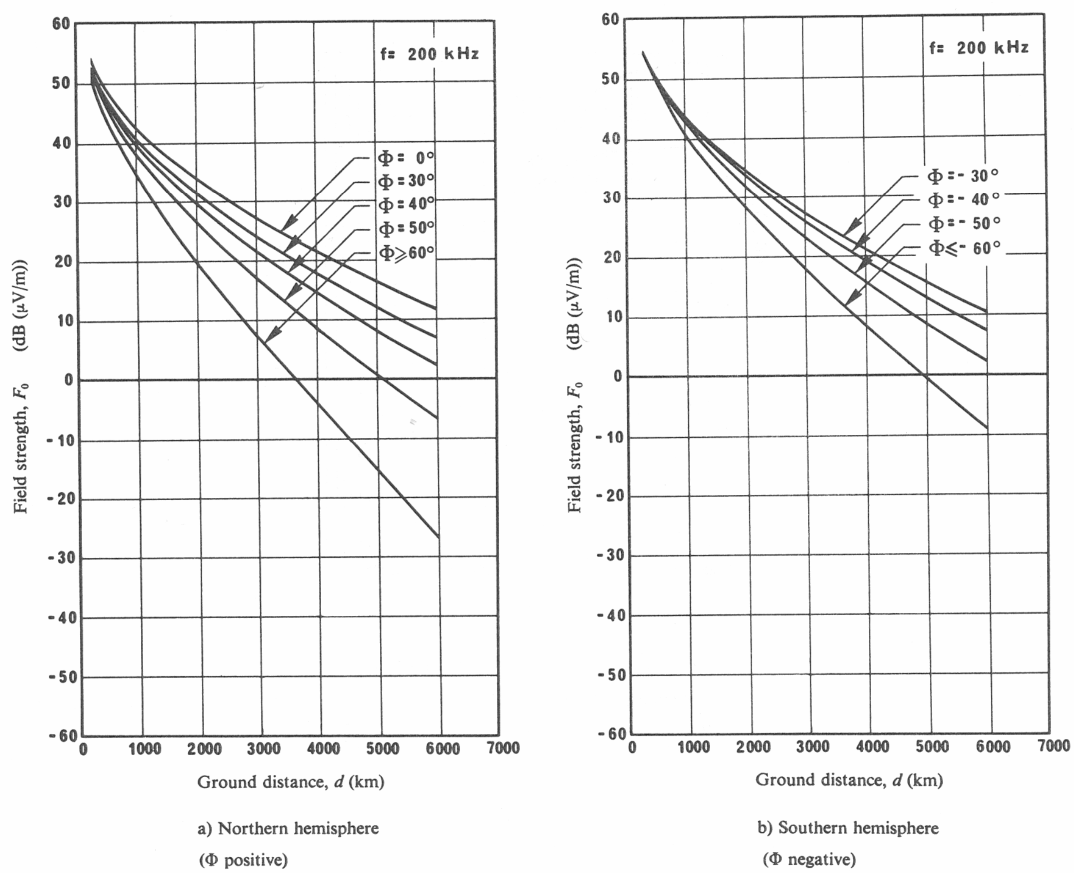

FIGURE 5 – *Curves showing F_0 for 200 kHz when G_S, L_P and R are all zero, for constant geomagnetic latitudes*