

RECOMMENDATION ITU-R PL.533-4

HF PROPAGATION PREDICTION METHOD*

(Question 223/3)

(1978-1982-1990-1992-1994)

The ITU Radiocommunication Assembly,

considering

- a) that the ex-CCIR developed and evaluated three separate computer-based methods of field-strength estimation as presented in Report ITU-R PL.252, Supplement to Report ITU-R PL.252, Report ITU-R PL.894 and Annex 1 of this Recommendation which has been derived from Report ITU-R PL.894;
- b) that tests against ITU-R Data Bank D1 show that the method of Annex 1 has comparable accuracy to the other more complex methods;
- c) that associated computer codes have been formulated and made available to the Radiocommunication Bureau (see Resolution ITU-R 63),

recommends

- 1. that the information contained in Annex 1 should be used in computerized prediction of sky-wave propagation at frequencies between 2-30 MHz;
- 2. that administrations and ITU-R should endeavour to improve prediction methods to enhance operational facilities and to improve accuracy.

ANNEX 1

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* A computer program associated with prediction procedures described in this Recommendation is available from the Radiocommunication Bureau; for details see Resolution ITU-R 63.

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1. Introduction

This propagation prediction method for use in the estimation of reliability and compatibility between frequencies of about 3 MHz and 30 MHz derives from a method first proposed in 1983 by CCIR Interim Working Party 6/12 with later refinements following considerations by the WARC for HF broadcasting, the CCIR, ITU-R, broadcasting and other organizations. The procedure applies a ray-path analysis for path lengths up to 7 000 km, composite mode empirical formulations from the fit to measured data beyond 9 000 km and a smooth transition between these two approaches over the 7 000-9 000 km distance range.

Monthly median basic MUF, incident sky-wave field strength and available receiver power from a lossless receiving antenna of given gain are determined. Signal strengths are standardized against an ITU-R measurement data bank. The method requires the determination of a number of ionospheric characteristics and propagation parameters at specified "control points".

A computer program in both mainframe and microcomputer versions has been developed for this prediction method. Information on the availability of the program is found in Resolution ITU-R 63.

2. Location of control points

Propagation is assumed to be along the great-circle path between the transmitter and receiver locations via E modes (up to 4 000 km range) and F2 modes (for all distances). Depending on path length and reflecting layer, control points are selected as indicated in Table 1.

3. Basic and operational maximum usable frequencies

The estimation of operational MUF, the highest frequency that would permit acceptable operation of a radio service, is in two stages: first, the estimation of basic MUF from a consideration of ionospheric parameters and second, the determination of a correction factor to allow for propagation mechanisms at frequencies above the basic MUF.

TABLE 1

Locations of control points for the determination of basic MUF, E-layer screening, ray-path mirror-reflection heights and ionospheric absorption

a) Basic MUF and associated electron gyrofrequency

Path length D (km)	E modes	F2 modes
$0 < D \leq 2\,000$	M	M
$2\,000 < D \leq 4\,000$	$T + 1\,000, R - 1\,000$	–
$2\,000 < D \leq d_{max}$	–	M
$D > d_{max}$	–	$T + d_0/2, R - d_0/2$

b) E-layer screening

Path length D (km)	F2 modes
$0 < D \leq 2\,000$	M
$2\,000 < D < 9\,000$	$T + 1\,000, R - 1\,000$

c) Ray-path mirror-reflection heights

Path length D (km)	F2 modes
$0 < D \leq d_{max}$	M
$d_{max} < D < 9\,000$	$T + d_0/2, M, R - d_0/2$

d) Ionospheric absorption and associated electron gyrofrequency

Path length D (km)	E modes	F2 modes
$0 < D \leq 2\,000$	M	M
$2\,000 < D \leq 4\,000$	$T + 1\,000, M, R - 1\,000$	–
$2\,000 < D \leq d_{max}$	–	$T + 1\,000, M, R - 1\,000$
$d_{max} < D < 9\,000$	–	$T + 1\,000, T + d_0/2, M, R - d_0/2, R - 1\,000$

M : path mid-point.
 T : transmitter location.
 R : receiver location.
 d_{max} : maximum F2 hop length.
 d_0 : hop length of lowest-order mode.

Distances are quoted in kilometres.

3.1 Basic maximum usable frequencies

The basic MUFs of the various propagation modes are evaluated in terms of the corresponding ionospheric layer critical frequencies and a factor related to hop length. Where both E and F2 modes are considered the higher of the two basic MUFs of the lowest-order E and F2 modes gives the basic MUF for the path.

3.2 E-layer critical frequency (foE)

foE is determined as defined in Recommendation ITU-R PI.434.

3.3 E-layer basic MUF

foE is evaluated at the control points noted in Table 1a) and for path lengths of 2 000–4 000 km the lower value is selected. The basic MUF of an n -hop E mode over a path of length D is given by:

$$n E(D)MUF = foE \cdot \sec i_{110} \quad (1)$$

where i_{110} is the angle of incidence at a mid-hop mirror-reflection height of 110 km for a hop of length $d = D/n$.

The E-layer basic MUF for the path is the value of $E(D)MUF$ for the lowest-order E-mode.

3.4 F2-layer characteristics

Numerical representations of the ionospheric characteristics foF2 and M(3000)F2, for solar-index values $R_{12} = 0$ and 100, and for each month are taken from Recommendation ITU-R PL.434 where the magnetic field is evaluated at a height of 300 km. The Oslo coefficients are used to determine these values for the required times and for the control points given in Table 1a). Linear interpolation or extrapolation is applied for the prevailing index values between $R_{12} = 0$ and 150 (see Recommendation ITU-R PL.371). For higher sunspot activity, R_{12} is set equal to 150 in the case of foF2 only.

3.5 F2-layer basic MUF

3.5.1 Lowest-order mode

3.5.1.1 Paths up to d_{max} (km)

The order, n_0 , of the lowest-order mode is determined by geometrical considerations, using the mirror reflection height h_r derived at the mid-path control point from the equation:

$$h_r = \frac{1\,490}{M(3000)F2} - 176 \text{ km or } 500 \text{ km, whichever is the smaller} \quad (2)$$

For this mode, the F2-layer basic MUF, which is also the F2-layer basic MUF for the path, is calculated as:

$$n_0 F2(D)MUF = \left[1 + \left(\frac{C_d}{C_{3000}} \right) (B - 1) \right] \cdot foF2 + \frac{f_H}{2} \left(1 - \frac{d}{d_{max}} \right) \quad (3)$$

where:

f_H : value of electron gyrofrequency, for a height of 300 km, determined at each of the appropriate control points given in Table 1a)

$$C_d = 0.74 - 0.591 Z - 0.424 Z^2 - 0.090 Z^3 + 0.088 Z^4 + 0.181 Z^5 + 0.096 Z^6 \quad (4)$$

with $Z = 1 - 2d/d_{max}$

$$d_{max} = 4\,780 + (12\,610 + 2\,140/x^2 - 49\,720/x^4 + 688\,900/x^6) (1/B - 0.303) \quad (5)$$

$$B = M(3000)F2 - 0.124 + \left[[M(3000)F2]^2 - 4 \right] \cdot \left[0.0215 + 0.005 \sin \left(\frac{7.854}{x} - 1.9635 \right) \right] \quad (6)$$

where:

$d = D/n_0$ and d_{max} are in kilometres

C_{3000} : value of C_d for $D = 3\,000$ km

$x = f_oF2/f_oE$, or 2, whichever is the larger

f_oE is calculated as in § 3.3.

3.5.1.2 *Paths longer than d_{max} (km)*

The basic MUF of the lowest-order mode $n_0F2(D)MUF$ for path length D is taken equal to the lower of the $F2(d_{max})MUF$ values determined from equation (3) for the two control points given in Table 1a). This is also the basic MUF for the path.

3.5.2 *Higher-order modes (paths up to 9 000 km)*

3.5.2.1 *Paths up to d_{max} (km)*

The F2-layer basic MUF for an n -hop mode is calculated using equations (3) to (6) at the midpath control point given in Table 1a) for hop length $d = D/n$.

3.5.2.2 *Paths longer than d_{max} (km)*

The F2-layer basic MUF for an n -hop mode is calculated in terms of $F2(d_{max})MUF$ and a distance scaling factor dependent on the respective hop lengths of the mode in question and the lowest possible order mode.

$$n\ F2(D)MUF = F2(d_{max})MUF \cdot M_n / M_{n_0} \tag{7}$$

where M_n/M_{n_0} is derived using equation (3) as follows:

$$\frac{M_n}{M_{n_0}} = \frac{n\ F2(d)MUF}{n_0\ F2(d)MUF} \tag{8}$$

The lower of the values calculated at the two control points of Table 1a) is selected.

3.6 *The path operational MUF*

The path operational MUF is the greater of the operational MUF for F2 modes and the operational MUF for E modes. For F2 modes, the operational MUF = basic MUF. R_{op} where R_{op} is given in Table 2 to Recommendation ITU-R PL.434. For E modes the operational MUF is equal to the basic MUF.

An estimate of the operational MUF exceeded for 10% and 90% of the days is determined by multiplying the median operational MUF by the factors 1.15 and 0.85 respectively in the case of the F modes and 1.05 and 0.95 respectively in the case of E modes.

4. **E-layer maximum screening frequency (f_s)**

E-layer screening of F2 modes is considered for paths up to 9 000 km. The f_oE value at the mid-point of the path (for paths up to 2 000 km), or the higher one of the f_oE values at the two control points 1 000 km from each end of the path (for paths longer than 2 000 km), is taken for the calculation of the maximum screening frequency (see Table 1b)).

$$f_s = 1.05\ f_oE\ \sec\ i \tag{9}$$

with:

$$i = \arcsin \left[\frac{R_0 \cos \Delta_F}{R_0 + h_r} \right] \tag{10}$$

where:

- i : angle of incidence at height $h_r = 110$ km
- R_0 : radius of the Earth, 6 371 km
- Δ_F : elevation angle for the F2-layer mode (determined from equation (11)).