

ITU-R

Radiocommunication Sector of ITU

Recommendation ITU-R P.533-13 (07/2015)

Method for the prediction of the performance of HF circuits

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.533-13

Method for the prediction of the performance of HF circuits*

(1978-1982-1990-1992-1994-1995-1999-2001-2005-2007-2009-2012-2013-2015)

Scope

This Recommendation provides a method for the prediction of available frequencies, of signal levels and of the predicted reliability for both analogue and digital modulated systems at HF, taking into account not only the signal-to-noise ratio but also the expected time and frequency spreads of the channel.

Keywords

Ionosphere, HF, prediction

The ITU Radiocommunication Assembly,

considering

- a) that tests against ITU-R Data Bank D1 show that the method of Annex 1 of this Recommendation has comparable accuracy to the other more complex methods;
- b) that information on the performance characteristics of transmitting and receiving antennas is required for the practical application of this method¹,

recommends

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

* A computer program (ITURHFProp) associated with the prediction procedures described in this Recommendation is available from that part of the ITU-R website dealing with Radiocommunication Study Group 3.

¹ Detailed information on a range of antennas with an associated computer program is available from the ITU; for details, see Recommendation ITU-R BS.705.

Annex 1

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1 Introduction

This prediction 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. The method includes an estimation of the parameters of the channel transfer function for use for the prediction of performance of digital systems. Methods are given for the assessment of circuit reliability. 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”.

In equatorial regions, in the evening hours (local time), it is possible to have distortions in the predicted results due to regional ionospheric structural instabilities which are not fully accounted for by this method.

PART 1

Frequency availability

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.

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 give the basic MUF for the path.

3.2 E-layer critical frequency (foE)

The monthly median foE is determined as defined in Recommendation ITU-R P.1239.

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 hop length for F2 mode calculated at the mid-path control point

d_0 : hop length of lowest-order mode

Distances are quoted in kilometres.

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 $n_0 E(D)MUF$ for the lowest-order E-mode, n_0 .

3.4 F2-layer characteristics

Numerical representations of the monthly median 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 P.1239 where the magnetic field is evaluated at a height of 300 km. These representations 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 160 (see Recommendation ITU-R P.371). For higher sunspot activity, R_{12} is set equal to 160 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 lowest-order mode, n_0 , is determined by geometrical considerations, using the mirror reflection height h_r derived at the mid-path control point from the equation:

$$h_r = \frac{1490}{M(3000)F2} - 176 \text{ km or } 500 \text{ km, whichever is the smaller} \quad (2)$$

For the n^{th} order mode, the F2-layer basic MUF is calculated as:

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

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

$$d_{max} = 4780 + (12610 + 2140/x^2 - 49720/x^4 + 688900/x^6) (1/B - 0.303) \quad (5)$$

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

where:

- d : D/n and d_{max} are in kilometres
- C_{3000} : value of C_d for $d = 3\,000$ km
- x : foF2/foE, or 2, whichever is the larger
foE is calculated as in § 3.2.

The $nF2(D)MUF$ for the lowest-order mode, n_0 , is the path basic MUF. For the calculation of the basic MUF d_{max} is restricted to be no greater than 4 000 km.

3.5.1.2 Paths longer than d_{max} (km)

The basic MUF of the lowest-order mode n_0 $F2(D)MUF$ 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. For the calculation of M_n and M_{n0} , the maximum hop distance, d_{max} , is recalculated at the control point and can be larger than 4 000 km.

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

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

$$\frac{M_n}{M_{n_0}} = \frac{n F2(D)MUF}{n_0 F2(D)MUF} \quad (8)$$

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

3.6 Within the month probability of ionospheric propagation support

In some cases, it may be sufficient to predict the probability of having sufficient ionization to support propagation over the path, without taking into account system and antenna characteristics and performance requirements. In such cases, the probability that the MUF exceeds the working frequency is required. Sections 3.3 and 3.5 above give the median values of MUF(50) for E and F2 propagation.

For F2 modes, the lower decile ratio, δ_l , of the MUF exceeded for 90% of the days of the month, MUF(90), to MUF(50) is given in Recommendation ITU-R P.1239, Table 2, as a function of local time, latitude, season and sunspot number.

For cases where the working frequency, f , is less than MUF(50), the probability of ionospheric support is given by:

$$F_{prob} = 130 - \frac{80}{1 + MUF(50)/(f \cdot \delta_l)} \quad \text{or} = 100, \text{ whichever is the smaller} \quad (9)$$