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Recommendation ITU-R P.1812-2

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A path-specific propagation prediction method for point-to-area terrestrial services in the VHF and UHF bands

P Series

Radiowave propagation

International Telecommunication Union

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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.1812-2

A path-specific propagation prediction method for point-to-area terrestrial services in the VHF and UHF bands

(Question ITU-R 203/3)

(2007-2009-2012)

Scope

This Recommendation describes a propagation prediction method suitable for terrestrial point-to-area services in the frequency range 30 MHz to 3 GHz. It predicts signal levels at the median of the multipath distribution exceeded for a given percentage of time, p%, in the range 1% $\leq p \leq$ 50% and a given percentage of locations, p_L, in the range 1% $\leq p_L \leq$ 99%. The method provides detailed analysis based on the terrain profile.

The method is suitable for predictions for radiocommunication systems utilizing terrestrial circuits having path lengths from 0.25 km up to about 3 000 km distance, with both terminals within approximately 3 km height above ground. It is not suitable for propagation predictions on either air-ground or space-Earth radio circuits.

This Recommendation complements Recommendation ITU-R P.1546.

The ITU Radiocommunication Assembly,

considering

a) that there is a need to give guidance to engineers in the planning of terrestrial radiocommunication services in the VHF and UHF bands;

b) that, for stations working in the same or adjacent frequency channels, the determination of the minimum geographical distance of separation required to avoid unacceptable interference due to long-distance terrestrial propagation is a matter of great importance,

noting

a) that Recommendation ITU-R P.528 provides guidance on the prediction of point-to-area path loss for the aeronautical mobile service for the frequency range 125 MHz to 30 GHz and the distance range up to 1 800 km;

b) that Recommendation ITU-R P.452 provides guidance on the detailed evaluation of microwave interference between stations on the surface of the Earth at frequencies above about 0.7 GHz;

c) that Recommendation ITU-R P.617 provides guidance on the prediction of point-to-point (P-P) path loss for trans-horizon radio-relay systems for the frequency range above 30 MHz and for the distance range 100 to 1 000 km;

d) that Recommendation ITU-R P.1411 provides guidance on prediction for short-range (up to 1 km) outdoor services;

e) that Recommendation ITU-R P.530 provides guidance on the prediction of P-P path loss for terrestrial LoS systems;

f) that Recommendation ITU-R P.1546 provides guidance on the prediction of point-to-area field strengths in the VHF and UHF bands based principally on statistical analyses of experimental data,

recommends

1 that the procedure given in Annex 1 should be used for the detailed evaluation of point-to-area signal levels in connection with these services.

Annex 1

1 Introduction

The propagation prediction method described in this Annex is recommended for the detailed evaluation of signal levels suitable for use in connection with terrestrial point-to-area services in the VHF and UHF bands. It predicts the signal level (i.e. electric field strength) exceeded for a given percentage, p%, of an average year in the range $1\% \leq p \leq 50\%$ and p_L% locations in the range $1\% \leq p_L \leq 99\%$. Therefore, this method may be used to predict both the service area and availability for a desired signal level (coverage), and the reductions in this service area and availability due to undesired, co- and/or adjacent-channel signals (interference).

The propagation model of this method is symmetric in the sense that it treats both radio terminals in the same manner. From the model's perspective, it does not matter which terminal is the transmitter and which is the receiver. However, for convenience in the model's description, the terms "transmitter" and "receiver" are used to denote the terminals at the start and end of the radio path, respectively.

The method is first described in terms of calculating basic transmission loss (dB) not exceeded for p% time for the median value of locations. The location variability and building entry loss elements are then characterized statistically with respect to receiver locations. A procedure is then given for converting to electric field strength (dB(μV/m)) for an effective radiated power of 1 kW.

This method is intended primarily for use with systems using low-gain antennas. However, the change in accuracy when high-gain antennas are used only affects the troposcatter element of the overall method, and the change in the predictions is small. For example, even with 40 dBi antennas at both ends of the link the over-estimation of troposcatter signals will amount to only about 1 dB.

The method is suitable for predictions for radiocommunication systems utilizing terrestrial circuits having path lengths from 0.25 km up to about 3 000 km distance, with both terminals within approximately 3 km height above ground. It is not suitable for propagation predictions on either air-ground or space-Earth radio circuits.

The propagation prediction method in this Annex is path-specific. Point-to-area predictions using this method consist of series of many P-P (i.e. transmitter-point-to-receiver-multipoint) predictions, uniformly distributed over notional service areas. The number of points should be large enough to ensure that the predicted values of basic transmission losses or field strengths thus obtained are reasonable estimates of the median values, with respect to locations, of the corresponding quantities for the elemental areas that they represent.

In consequence, it is assumed that users of this Recommendation are able to specify detailed terrain profiles (i.e. elevations above mean sea level) as functions of distance along the great circle paths (i.e. geodesic curves) between the terminals, for many different terminal locations (receiver-points).

For most practical applications of this method to point-to-area coverage and interference predictions, this assumption implies the availability of a digital terrain elevation database, referenced to latitude and longitude with respect to a consistent geodetic datum, from which the terrain profiles may be extracted by automated means. If these detailed terrain profiles are not available, then Recommendation ITU-R P.1546 should instead be used for predictions.

In view of the foregoing, the location variability and building entry loss model elements of this Recommendation are characterized via the statistics of lognormal distributions with respect to receiver locations. Although this statistical characterization of the point-to-area propagation problem would appear to make the overall model unsymmetrical (i.e. non-reciprocal), users of this Recommendation should note that the location variability could, in principle, be applied at either end of the path (i.e. either terminal), or even both (i.e. the transmitter and the receiver). However, the location variability correction is only meaningful in situations when exact location of a given terminal is unknown and a statistical representation over that terminal's potential locations is required. There are unlikely to be many situations where this could meaningfully be applied to the transmitter location. If the locations of both terminals are known exactly and this procedure is being used in P-P mode, then this Recommendation is only applicable with p_L = 50%.

A similar point is true regarding building entry losses. The argument is slightly more complicated than for location variability owing to the fact that the median entry loss correction is non-zero. At the transmitter end, users should also add the building entry loss to the basic transmission loss if the transmitter is inside a building, but users must also be aware that the median loss values in Table 6 may be misleading if the transmitter is not in a "median" location.

2 Model elements of the propagation prediction method

This propagation prediction method takes account of the following model elements:

– *line-of-sight* (LoS)
– *diffraction* (embracing smooth-Earth, irregular terrain and sub-path cases)
– *tropospheric scatter*
– *anomalous propagation* (ducting and layer reflection/refraction)
– *height-gain variation in clutter*
– *location variability*
– *building entry losses.*

3 Input parameters

3.1 Basic input data

Table 1 describes the basic input data, which defines the radio terminals, the frequency, and the percentage time and locations for which a prediction is required.

The latitude and longitude of the two stations are stated as basic inputs on the basis that they are needed to obtain the path profile. Radio-meteorological parameters must be obtained for a single location associated with the radio path, and for a long path the path-centre should be selected. It is appropriate to obtain the radio-meteorological parameters for the transmitter location when predicting its coverage area.

TABLE 1

Basic input data

Parameter	Units	Minimum	Maximum	Description
f	GHz	0.03	3.0	Frequency (GHz)
p	%	1.0	50.0	Percentage of average year for which the calculated signal level is exceeded
p_L	%	1	99	Percentage of locations for which the calculated signal level is exceeded
φ_t, φ_r	degrees	−80	+80	Latitude of transmitter, receiver
ψ_t, ψ_r	degrees	−180.0	180.0	Longitude of transmitter, receiver (positive = East of Greenwich)
h_{tg}, h_{rg}	m	1	3 000	Antenna centre height above ground level

3.2 Terrain profile

A terrain profile for the radio path is required for the application of the propagation prediction method. In principle, this consists of three arrays each having the same number of values, n, as follows:

d_i: distance from transmitter of i-th profilepoint (km) (1a)

h_i: height of i-th profilepoint above sealevel (m) (1b)

$g_i = h_i$ + representative clutter height of i-th profilepoint (m) (1c)

where:

i: 1, 2, 3 ... n = index of the profile point

n: number of profile points.

Note that the first profile point is at the transmitter. Thus d_1 is zero and h_1 is the terrain height at the transmitter in metres above sea level. Similarly, the n-th profile point is at the receiver. Thus d_n is the path length in km, and h_n the terrain height at the receiver in metres above sea level.

No specific distance between profile points is given. Assuming that profiles are extracted from a digital terrain elevation model, a suitable spacing will typically be similar to the point spacing of the source data. The profile points are not required to be equally-spaced, but it is desirable that they are at a similar spacing for the whole profile.

It is desirable to have information on ground cover (clutter) along the path. It is convenient to store clutter categories in an additional array of n points to match the profile height data.

The “representative clutter height” referred to in equation (1c) concerns ground cover, such as vegetation and buildings. Adding clutter heights to a profile is based on the assumption that the heights h_i represent the bare surface of the Earth. If the radio path passes over woodland or urbanization where diffraction or sub-path obstruction occurs, in general the effective profile height will be higher because the radio signal will travel over the clutter. Thus a more accurate representation of the profile can be obtained by adding heights to account for the clutter.

The appropriate addition is not necessarily physical, such as rooftop heights in the case of buildings. Where gaps exist between clutter objects, as seen by the radio wave, some energy may travel between rather than over them. In this situation the presence of clutter is expected to increase diffraction loss, but not by as much as raising the profile to the physical clutter height.

This applies particularly to high-rise urban areas. Categories such as "dense urban" or "high-rise urban" tend to be associated with building heights of 30 metres or more. But some high-rise areas have large spaces between the tall buildings, and it is possible for low-loss paths to exist passing around them, rather than over the roofs.

At the other extreme, even in areas classified as "open" or "rural" it is unusual for the ground to be completely bare, that is, free of any objects which might add to propagation losses. Thus small values of R, rather than zero, might be appropriate in many cases.

There is a separate use of clutter information to estimate terminal clutter losses, as described in § 4.7. The concept of representative clutter height, R, is retained, but may be interpreted differently. Particularly for urban categories the objective is to identify the height over which the signal must propagate for a terminal below clutter height. In such cases an estimate should again be made as to what extent, on a statistical basis, the signal passes around rather than over clutter objects. In the case of open, rural and water categories, R is essentially a scaling factor for equation (54b).

Thus representative clutter height R depends not only on the typical physical height of clutter objects but also on the horizontal spacing of objects and the gaps between them. There is no accepted standard as to what a clutter category, such as "urban", represents in physical terms in different countries. Table 2 suggests default values for R which may be used in the absence of more specific information appropriate for the region concerned.

TABLE 2

Default information for clutter-loss modelling

Clutter type	Representative clutter height (m)		Terminal clutter loss model
	Add to profile equation (1c)	**Terminal clutter losses § 4.7**	
Water/sea	0	10	Equation (64b)
Open/rural	0	10	Equation (64b)
Suburban	10	10	Equation (64a)
Urban/trees/forest	15	15	Equation (64a)
Dense urban	20	20	Equation (64a)

3.3 Radio-climatic zones

Information is also needed on what lengths of the path are in the radio-climatic zones described in Table 3.

For maximum consistency of results between administrations it is strongly recommended that the calculations of this procedure be based on the ITU Digitized World Map (IDWM) which is available from the BR for mainframe or personal computer environments. If all points on the path are at least 50 km from the sea or other large bodies of water, then only the inland category applies.

If the zone information is stored in successive points along the radio path, it should be assumed that changes occur midway between points having different zone codes.

TABLE 3

Radio-climatic zones

Zone type	Code	Definition
Coastal land	A1	Coastal land and shore areas, i.e. land adjacent to the sea up to an altitude of 100 m relative to mean sea or water level, but limited to a distance of 50 km from the nearest sea area. Where precise 100 m data are not available an approximate value may be used
Inland	A2	All land, other than coastal and shore areas defined as "coastal land" above
Sea	B	Seas, oceans and other large bodies of water (i.e. covering a circle of at least 100 km in diameter)

3.4 Terminal distances from the coast

If the path is over zone B two further parameters are required, d_{ct}, d_{cr}, giving the distance of the transmitter and the receiver from the coast (km), respectively, in the direction of the other terminal. For a terminal on a ship or sea platform the distance is zero.

3.5 Basic radio-meteorological parameters

The prediction procedure requires two radio-meteorological parameters to describe the variability of atmospheric refractivity.

– ΔN (N-units/km), the average radio-refractive index lapse-rate through the lowest 1 km of the atmosphere, provides the data upon which the appropriate effective Earth radius can be calculated for path profile and diffraction obstacle analysis. Note that ΔN is a positive quantity in this procedure.

– N_0 (N-units), the sea-level surface refractivity, is used only by the troposcatter model as a measure of variability of the troposcatter mechanism.

Appendix 1 gives global maps of ΔN and N_0, and data files containing the digitized maps are available from the Bureau.

3.6 Incidence of ducting

The degree to which signal levels will be enhanced due to anomalous propagation, particularly ducting, is quantified by a parameter β_0 (%), the time percentage for which refractive index lapse-rates exceeding 100 N-units/km can be expected in the first 100 m of the lower atmosphere. The value of β_0 is calculated as follows.

Calculate the parameter μ_1, which depends on the degree to which the path is over land (inland and/or coastal) and water:

$$\mu_1 = \left(10^{\frac{-d_{tm}}{16-6.6\tau}} + 10^{-5\cdot(0.496+0.354\tau)} \right)^{0.2} \tag{2}$$

where the value of μ_1 shall be limited to $\mu_1 \leq 1$, and

$$\tau = 1 - e^{-\left(4.12 \times 10^{-4} \times d_{lm}^{2.41}\right)} \tag{3}$$

d_{tm}: longest continuous land (inland + coastal) section of the great-circle path (km)

d_{lm}: longest continuous inland section of the great-circle path (km).

The radio-climatic zones to be used for the derivation of d_{tm} and d_{lm} are defined in Table 3. If all points on the path are at least 50 km from the sea or other large bodies of water, then only the inland category applies and d_{tm} and d_{lm} are equal to the path length, d.

Calculate the parameter μ_4, which depends on μ_1 and the latitude of the path centre in degrees:

$$\begin{aligned} \mu_4 &= \mu_1^{(-0.935 + 0.0176|\varphi|)} && \text{for } |\varphi| \le 70° \\ \mu_4 &= \mu_1^{0.3} && \text{for } |\varphi| > 70° \end{aligned} \tag{4}$$

where:

φ: path centre latitude (degrees).

Calculate β_0:

$$\beta_0 = \begin{cases} 10^{-0.015|\varphi| + 1.67}\mu_1 \mu_4 & \% \quad \text{for } |\varphi| \le 70° \\ 4.17\mu_1 \mu_4 & \% \quad \text{for } |\varphi| > 70° \end{cases} \tag{5}$$

3.7 Effective Earth radius

The median effective Earth radius factor k_{50} for the path is given by:

$$k_{50} = \frac{157}{157 - \Delta N} \tag{6}$$

The value of the average radio-refractivity lapse-rate, ΔN, may be obtained from Fig. 1, using the latitude and longitude of the path centre as representative for the entire path.

The median value of effective Earth radius a_e is given by:

$$a_e = 6\,371 \cdot k_{50} \qquad \text{km} \tag{7a}$$

The effective Earth radius exceeded for β_0 time, a_β, is given by:

$$a_\beta = 6\,371 \cdot k_\beta \qquad \text{km} \tag{7b}$$

where $k_\beta = 3.0$ is an estimate of the effective Earth-radius factor exceeded for β_0 time.

3.8 Parameters derived from the path profile analysis

Values for a number of path-related parameters necessary for the calculations, as indicated in Table 4, must be derived via an initial analysis of the path profile based on the value of a_e given by equation (7a). Information on the derivation, construction and analysis of the path profile is given in Appendix 2 of this Annex.

4 The prediction procedure

4.1 General

The overall prediction procedure is described in this section. First, the basic transmission loss, L_b (dB), not exceeded for the required annual percentage time, p%, and 50% locations is evaluated as described in § 4.2-4.6 (i.e. the basic transmission losses due to LoS propagation, propagation by diffraction, propagation by tropospheric scatter, propagation by ducting/layer reflection and the combination of these propagation mechanisms to predict the basic transmission loss, respectively). In § 4.7-4.10, methods to account for the inclusion of terminal clutter effects, the effects of location variability and building entry loss are described. Finally, § 4.11 gives expressions that relate the basic transmission loss to the field strength (dB μV/m) for 1 kW effective radiated power.

TABLE 4

Parameter values to be derived from the path profile analysis

Parameter	Description
d	Great-circle path distance (km)
d_{lt}, d_{lr}	Distance from the transmit and receive antennas to their respective horizons (km)
θ_t, θ_r	Transmit and receive horizon elevation angles respectively (mrad)
θ	Path angular distance (mrad)
h_{ts}, h_{rs}	Antenna centre height above mean sea level (m)
h_{tc}, h_{rc}	max(h_{ts}, g_1) and max(h_{rs}, g_n) respectively
h_{te}, h_{re}	Effective heights of antennas above the terrain (m)
d_b	Aggregate length of the path sections over water (km)
ω	Fraction of the total path over water: $$\omega = d_b / d$$ where d is the great-circle distance (km) calculated using equation (73). For totally overland paths: $\omega = 0$

4.2 Line-of-sight propagation (including short-term effects)

The following should all be evaluated for both LoS and trans-horizon paths.

The basic transmission loss due to free-space propagation is given by:

$$L_{bfs} = 92.44 + 20 \log f + 20 \log d \qquad \text{dB} \tag{8}$$

Corrections for multipath and focusing effects at p and β_0 percentage times, respectively, are given by:

$$E_{sp} = 2.6 \left(1 - e^{-\frac{d_{lt} + d_{lr}}{10}}\right) \log\left(\frac{p}{50}\right) \qquad \text{dB} \tag{9a}$$

$$E_{s\beta} = 2.6 \left(1 - e^{-\frac{d_{lt} + d_{lr}}{10}}\right) \log\left(\frac{\beta_0}{50}\right) \qquad \text{dB} \tag{9b}$$

Calculate the basic transmission loss not exceeded for time percentage, p%, due to LoS propagation (regardless of whether or not the path is actually LoS), as given by:

$$L_{b0p} = L_{bfs} + E_{sp} \qquad \text{dB} \tag{10}$$

Calculate the basic transmission loss not exceeded for time percentage, β_0%, due to LoS propagation (regardless of whether or not the path is actually LoS), as given by:

$$L_{b0\beta} = L_{bfs} + E_{s\beta} \qquad \text{dB} \tag{11}$$

4.3 Propagation by diffraction

Diffraction loss is calculated by the combination of a method based on the Bullington construction and spherical-Earth diffraction. The Bullington part of the method is an expansion of the basic Bullington construction to control the transition between free-space and obstructed conditions. This part of the method is used twice: for the actual path profile, and for a zero-height smooth profile with modified antenna heights referred to as effective antenna heights. The same effective antenna heights are also used to calculate spherical-earth diffraction loss. The final result is obtained as a combination of three losses calculated as above. For a perfectly smooth path the final diffraction loss will be the output of the spherical-Earth model.

This method provides an estimate of diffraction loss for all types of path, including over-sea or over-inland or coastal land, and irrespective of whether the path is smooth or rough, and whether LoS or transhorizon.

This diffraction method is always used for median effective Earth radius. If an overall prediction is required for p = 50%, no further diffraction calculation is necessary.

In the general case where p < 50%, the diffraction calculation must be performed a second time for an effective Earth-radius factor equal to 3. This second calculation gives an estimate of diffraction loss not exceeded for β_0% time, where β_0 is given by equation (5).

The diffraction loss not exceeded for p% time, for 1% ≤ p ≤ 50%, is then calculated using a limiting or interpolation procedure described in § 4.3.5.

The method uses an approximation to the single knife-edge diffraction loss as a function of the dimensionless parameter, ν, given by:

$$J(\nu) = 6.9 + 20\log\left(\sqrt{(\nu - 0.1)^2 + 1} + \nu - 0.1\right) \tag{12}$$

Note that $J(-0.78) \approx 0$, and this defines the lower limit at which this approximation should be used. $J(\nu)$ is set to zero for $\nu \leq -0.78$.

The overall diffraction calculation is described in sub-sections as follows:

Section 4.3.1 describes the Bullington part of the diffraction method. For each diffraction calculation for a given effective Earth radius this is used twice. On the second occasion the antenna heights are modified and all profile heights are zero.

Section 4.3.2 describes the spherical-Earth part of the diffraction model. This is used with the same antenna heights as for the second use of the Bullington part in § 4.3.1.

Section 4.3.3 describes how the methods in § 4.3.1 and § 4.3.2 are used in combination to perform the complete diffraction calculation for a given effective Earth radius. Due to the manner in which the Bullington and spherical-earth parts are used, the complete calculation has come to be known as the "delta-Bullington" model.

Section 4.3.4 describes the complete calculation for diffraction loss not exceeded for a given percentage time p%.

4.3.1 The Bullington part of the diffraction calculation

In the following equations slopes are calculated in m/km relative to the baseline joining sea level at the transmitter to sea level at the receiver. The distance and height of the i-th profile point are d_i kilometres and h_i metres above sea level respectively, i takes values from 1 to n where n is the number of profile points, and the complete path length is d kilometres. For convenience the terminals at the start and end of the profile are referred to as transmitter and receiver, with heights in metres above sea level h_{ts} and h_{rs}, respectively. Effective Earth curvature C_e km^{-1} is given by $1/a_e$ where a_e is effective earth radius in kilometres. Wavelength in metres is represented by λ.

Find the intermediate profile point with the highest slope of the line from the transmitter to the point.

$$S_{tim} = \max\left[\frac{h_i + 500 C_e d_i (d - d_i) - h_{tc}}{d_i}\right] \qquad \text{m/km} \qquad (13)$$

where the profile index i takes values from 2 to n-1.

Calculate the slope of the line from transmitter to receiver assuming a LoS path:

$$S_{tr} = \frac{h_{rc} - h_{tc}}{d} \qquad \text{m/km} \qquad (14)$$

Two cases must now be considered.

Case 1. Path is LoS

If $S_{tim} < S_{tr}$ the path is LoS.

Find the intermediate profile point with the highest diffraction parameter ν:

$$\nu_{\max} = \max\left\{\left[h_i + 500 C_e d_i (d - d_i) - \frac{h_{tc}(d - d_i) + h_{rc} d_i}{d}\right]\sqrt{\frac{0.002 d}{\lambda d_i (d - d_i)}}\right\} \qquad (15)$$

where the profile index i takes values from 2 to n-1.

In this case, the knife-edge loss for the Bullington point is given by:

$$L_{uc} = J(\nu_{\max}) \qquad \text{dB} \qquad (16)$$

where the function J is given by equation (12) for ν_b greater than -0.78, and is zero otherwise.

Case 2. Path is transhorizon

If $S_{tim} \geq S_{tr}$ the path is transhorizon.

Find the intermediate profile point with the highest slope of the line from the receiver to the point.

$$S_{rim} = \max\left[\frac{h_i + 500 C_e d_i (d - d_i) - h_{rc}}{d - d_i}\right] \qquad \text{m/km} \qquad (17)$$

where the profile index i takes values from 2 to n-1.

Calculate the distance of the Bullington point from the transmitter:

$$d_{bp} = \frac{h_{rc} - h_{tc} + S_{rim} d}{S_{tim} + S_{rim}} \qquad \text{km} \tag{18}$$

Calculate the diffraction parameter, ν_b, for the Bullington point:

$$\nu_b = \left[h_{tc} + S_{tim} d_{bp} - \frac{h_{tc}(d - d_b) + h_{rc} d_{bp}}{d} \right] \sqrt{\frac{0.002d}{\lambda d_b (d - d_{bp})}} \tag{19}$$

In this case, the knife-edge loss for the Bullington point is given by:

$$L_{uc} = J(\nu_b) \qquad \text{dB} \tag{20}$$

For L_{uc} calculated using either equation (16) or (20), Bullington diffraction loss for the path is now given by:

$$L_{bull} = L_{uc} + [1 - \exp(-L_{uc}/6)](10 + 0.02d) \qquad \text{dB} \tag{21}$$

4.3.2 Spherical-Earth diffraction loss

The spherical-Earth diffraction loss not exceeded for p% time for antenna heights h_{te} and h_{re} (m), L_{dsph}, is calculated as follows.

Calculate the marginal LoS distance for a smooth path:

$$d_{los} = \sqrt{2a_p} \cdot \left(\sqrt{0.001 h_{te}} + \sqrt{0.001 h_{re}} \right) \qquad \text{km} \tag{22}$$

If $d \geq d_{los}$ calculate diffraction loss using the method in § 4.3.3 below for $a_{dft} = a_p$ to give L_{dft}, and set L_{dsph} equal to L_{dft}. No further spherical-Earth diffraction calculation is necessary.

Otherwise continue as follows:

Calculate the smallest clearance height between the curved-Earth path and the ray between the antennas, h, given by:

$$h_{se} = \frac{\left(h_{te} - 500 \frac{d_{se1}^2}{a_p} \right) d_2 + \left(h_{re} - 500 \frac{d_{se2}^2}{a_p} \right) d_1}{d} \qquad \text{m} \tag{23}$$

where

$$d_{se1} = \frac{d}{2}(1 + b) \qquad \text{km} \tag{24a}$$

$$d_{se2} = d - d_{se1} \qquad \text{km} \tag{24b}$$

$$b = 2\sqrt{\frac{m+1}{3m}} \cos \left\{ \frac{\pi}{3} + \frac{1}{3} \arccos \left(\frac{3c}{2} \sqrt{\frac{3m}{(m+1)^3}} \right) \right\} \tag{24c}$$

where the arccos function returns an angle in radians

$$c = \frac{h_{te} - h_{re}}{h_{te} + h_{re}} \tag{24d}$$

$$m = \frac{250d^2}{a_p(h_{te} + h_{re})} \tag{24e}$$

Calculate the required clearance for zero diffraction loss, h_{req}, given by:

$$h_{req} = 17.456\sqrt{\frac{d_{se1} \cdot d_{se2} \cdot \lambda}{d}} \quad \text{m} \tag{25}$$

If $h > h_{req}$ the spherical-Earth diffraction loss L_{dsph} is zero. No further spherical-Earth diffraction calculation is necessary.

Otherwise continue as follows:

Calculate the modified effective Earth radius, a_{em}, which gives marginal LoS at distance d given by:

$$a_{em} = 500\left(\frac{d}{\sqrt{h_{te}} + \sqrt{h_{re}}}\right)^2 \quad \text{km} \tag{26}$$

Use the method in § 4.3.3 for $a_{dft} = a_{em}$ to give L_{dft}.

If L_{dft} is negative, the spherical-Earth diffraction loss L_{dsph} is zero, and no further spherical-Earth diffraction calculation is necessary.

Otherwise continue as follows:

Calculate the spherical-Earth diffraction loss by interpolation:

$$L_{dsph} = \left[1 - h_{se} / h_{req}\right] L_{dft} \quad \text{dB} \tag{27}$$

4.3.3 First-term part of spherical-Earth diffraction loss

This sub-section gives the method for calculating spherical-Earth diffraction using only the first term of the residue series. It forms part of the overall diffraction method described in § 4.3.2 above to give the first-term diffraction loss L_{dft} for a given value of effective Earth radius a_{dft}. The value of a_{dft} to use is given in § 4.3.2.

Set terrain electrical properties typical for land, with relative permittivity $\varepsilon_r = 22.0$ and conductivity $\sigma = 0.003$ S/m and calculate L_{dft} using equations (29) to (36) and call the result $L_{dftland}$.

Set terrain electrical properties typical for sea, with relative permittivity $\varepsilon_r = 80.0$ and conductivity $\sigma = 5.0$ S/m and calculate L_{dft} using equations (29) to (36) and call the result L_{dftsea}.

First-term spherical diffraction loss is now given by:

$$L_{dft} = \omega L_{dftsea} + (1 - \omega) L_{dftland} \quad \text{dB} \tag{28}$$

where ω is the fraction of the path over sea.

Start of calculation to be performed twice, as described above:

Normalized factor for surface admittance for horizontal and vertical polarization:

$$K_H = 0.036\left(a_{dft} f\right)^{-1/3}\left[(\varepsilon_r - 1)^2 + (18\,\sigma / f)^2\right]^{-1/4} \quad \text{(horizontal)} \tag{29a}$$

and

$$K_V = K_H\left[\varepsilon_r^2 + (18\,\sigma / f)^2\right]^{1/2} \quad \text{(vertical)} \tag{29b}$$

Calculate the Earth ground/polarization parameter:

$$\beta_{dft} = \frac{1 + 1.6K^2 + 0.67K^4}{1 + 4.5K^2 + 1.53K^4} \tag{30}$$

where K is K_H or K_V according to polarization.

Normalized distance:

$$X = 21.88\,\beta_{dft}\left(\frac{f}{a_{dft}^2}\right)^{1/3} d \tag{31}$$

Normalized transmitter and receiver heights:

$$Y_t = 0.9575\,\beta_{dft}\left(\frac{f^2}{a_{dft}}\right)^{1/3} h_{te} \tag{32a}$$

$$Y_r = 0.9575\,\beta_{dft}\left(\frac{f^2}{a_{dft}}\right)^{1/3} h_{re} \tag{32b}$$

Calculate the distance term given by:

$$F_X = \begin{cases} 11 + 10\log(X) - 17.6X & \text{for } X \geq 1.6 \\ -20\log(X) - 5.6488X^{1.425} & \text{for } X < 1.6 \end{cases} \tag{33}$$

Define a function of normalized height given by:

$$G(Y) = \begin{cases} 17.6(B - 1.1)^{0.5} - 5\log(B - 1.1) - 8 & \text{for } B > 2 \\ 20\log(B + 0.1B^3) & \text{otherwise} \end{cases} \tag{34}$$

where:

$$B = \beta_{dft}\,Y \tag{35}$$

Limit $G(Y)$ such that $G(Y) \geq 2 + 20\log K$

The first-term spherical-Earth diffraction loss is now given by:

$$L_{dft} = -F_X - G(Y_t) - G(Y_r) \qquad \text{dB} \tag{36}$$

4.3.4 Complete "delta-Bullington" diffraction loss model

Use the method in § 4.3.1 for the actual terrain profile and antenna heights. Set the resulting Bullington diffraction loss for the actual path, $L_{bulla} = L_{bull}$ as given by equation (21).

Use the method in § 4.3.1 for a second time, with all profile heights, g_i, set to zero, and modified antenna heights given by

$$h'_{ts} = h_{ts} - h_{std} \quad \text{masl} \tag{37a}$$

$$h'_{rs} = h_{rs} - h_{srd} \quad \text{masl} \tag{37b}$$

where the smooth-Earth heights at transmitter and receiver, h_{std} and h_{srd}, are given in § 5.1.6.3 of Appendix 2. Set the resulting Bullington diffraction loss for this smooth path, $L_{bulls} = L_{bull}$ as given by equation (21).

Use the method in § 4.3.2 to calculate the spherical-Earth diffraction loss L_{dsph} for the actual path length d km and with:

$$h_{te} = h'_{ts} \quad \text{m} \tag{38a}$$

$$h_{re} = h'_{rs} \quad \text{m} \tag{38b}$$

Diffraction loss for the general path is now given by:

$$L_d = L_{bulla} + \max\{L_{dsph} - L_{bulls}\ , 0\} \qquad \text{dB} \tag{39}$$

4.3.5 The diffraction loss not exceeded for *p*% of the time

Use the method in § 4.3.4 to calculate diffraction loss L_d for median effective Earth radius a_e as given by equation (7a). Set median diffraction loss $L_{d50} = L_d$.

If p = 50% the diffraction loss not exceeded for p% time, L_{dp}, is given by L_{d50}, and this completes the diffraction calculation.

If p < 50%, continue as follows.

Use the method in § 4.3.4 to calculate diffraction loss L_d for effective Earth radius not exceeded for β_0% time a_β as given by equation(7b). Set diffraction loss not exceeded for β_0% time $L_{d\beta} = L_d$.

The application of the two possible values of effective Earth radius factor is controlled by an interpolation factor, F_i, based on a log-normal distribution of diffraction loss over the range $\beta_0\% < p \leq 50\%$, given by:

$$F_i = 0 \quad \text{if } p = 50\% \tag{40a}$$

$$= \frac{I\left(\dfrac{p}{100}\right)}{I\left(\dfrac{\beta_0}{100}\right)} \qquad \text{if } 50\% > p > \beta_0\% \tag{40b}$$

$$= 1 \quad \text{if } \beta_0\% \geq p \tag{40c}$$

where $I(x)$ is the inverse complementary cumulative normal distribution as a function of the probability x. An approximation for $I(x)$ which may be used with confidence for $x \leq 0.5$ is given in Appendix 3 to this Annex.

The diffraction loss, L_{dp}, not exceeded for p% time, is now given by:

$$L_{dp} = L_{d50} + (L_{d\beta} - L_{d50})\ F_i \qquad \text{dB} \qquad (41)$$

F_i is defined by equations (40a-c), depending on the values of p and β_0.

The median basic transmission loss associated with diffraction, L_{bd50}, is given by:

$$L_{bd50} = L_{bfs} + L_{d50} \qquad \text{dB} \qquad (42)$$

where L_{bfs} is given by equation (8).

The basic transmission loss associated with diffraction not exceeded for p% time is given by:

$$L_{bd} = L_{b0p} + L_{dp} \qquad \text{dB} \qquad (43)$$

where L_{b0p} is given by equation (10).

4.4 Propagation by tropospheric scatter

NOTE 1 – At time percentages much below 50%, it is difficult to separate the true tropospheric scatter mode from other secondary propagation phenomena which give rise to similar propagation effects. The "tropospheric scatter" model adopted in this Recommendation is therefore an empirical generalization of the concept of tropospheric scatter which also embraces these secondary propagation effects. This allows a continuous consistent prediction of basic transmission loss over the range of time percentages p from 0.001% to 50%, thus linking the ducting and layer reflection model at the small time percentages with the true "scatter mode" appropriate to the weak residual field exceeded for the largest time percentage.

NOTE 2 – This troposcatter prediction model has been derived for interference prediction purposes and is not appropriate for the calculation of propagation conditions above 50% of time affecting the performance aspects of trans-horizon radio-relay systems.

The basic transmission loss due to troposcatter, L_{bs} (dB), not exceeded for any time percentage, p, below 50%, is given by:

$$L_{bs} = 190.1 + L_f + 20\log d + 0.573\,\theta - 0.15\,N_0 - 10.125\left(\log\left(\frac{50}{p}\right)\right)^{0.7} \qquad \text{dB} \qquad (44)$$

where:

L_f: frequency dependent loss:

$$L_f = 25\log(f) - 2.5\left[\log\left(\frac{f}{2}\right)\right]^2 \qquad \text{dB} \qquad (45)$$

N_0: path centre sea-level surface refractivity, which may be derived from Fig. 2.

4.5 Propagation by ducting/layer reflection

The basic transmission loss associated with ducting/layer-reflection not exceeded for p% time, L_{ba} (dB), is given by:

$$L_{ba} = A_f + A_d(p) \qquad \text{dB} \qquad (46)$$

where:

A_f : total of fixed coupling losses (except for local clutter losses) between the antennas and the anomalous propagation structure within the atmosphere:

$$A_f = 102.45 + 20\log f + 20\log(d_{lt} + d_{lr}) + A_{lf} + A_{st} + A_{sr} + A_{ct} + A_{cr} \quad \text{dB} \tag{47}$$

A_{lf}: empirical correction to account for the increasing attenuation with wavelength in ducted propagation

$$A_{lf}(f) = 45.375 - 137.0\,f + 92.5\,f^2 \quad \text{dB} \quad \text{if } f < 0.5 \text{ GHz} \tag{47a}$$

$$A_{lf}(f) = 0.0 \text{ dB} \quad \text{otherwise}$$

A_{st}, A_{sr}: site-shielding diffraction losses for the transmitting and receiving stations respectively:

$$A_{st,sr} = \begin{cases} 20\log\left(1 + 0.361\,\theta''_{t,r}\,\left(f \cdot d_{lt,lr}\right)^{1/2}\right) + 0.264\,\theta''_{t,r}\,f^{1/3} & \text{dB} \quad \text{for } \theta''_{t,r} > 0 \text{ mrad} \\ 0 & \text{dB} \quad \text{for } \theta''_{t,r} \le 0 \text{ mrad} \end{cases} \tag{48}$$

where:

$$\theta''_{t,r} = \theta_{t,r} - 0.1\,d_{lt,lr} \quad \text{mrad} \tag{48a}$$

A_{ct}, A_{cr}: over-sea surface duct coupling corrections for the transmitting and receiving stations respectively:

$$A_{ct,cr} = -3\,e^{-0.25 d_{ct,cr}^2}\left(1 + \tanh(0.07(50 - h_{ts,rs}))\right) \quad \text{dB} \quad \text{for} \quad \omega \ge 0.75$$

$$d_{ct,cr} \le d_{lt,lr} \tag{49}$$

$$d_{ct,cr} \le 5 \text{ km}$$

$$A_{ct,cr} = 0 \quad \text{dB} \quad \text{for all other conditions} \tag{49a}$$

It is useful to note the limited set of conditions under which equation (49) is needed.

$A_d(p)$: time percentage and angular-distance dependent losses within the anomalous propagation mechanism:

$$A_d(p) = \gamma_d \cdot \theta' + A(p) \quad \text{dB} \tag{50}$$

where:

γ_d : specific attenuation:

$$\gamma_d = 5 \times 10^{-5}\,a_e f^{1/3} \quad \text{dB/mrad} \tag{51}$$

θ': angular distance (corrected where appropriate (via equation (48a)) to allow for the application of the site shielding model in equation (46)):

$$\theta' = \frac{10^3 d}{a_e} + \theta'_t + \theta'_r \quad \text{mrad} \tag{52}$$

$$\theta'_{t,r} = \begin{cases} \theta_{t,r} & \text{for } \theta_{t,r} \le 0.1\,d_{lt,lr} \quad \text{mrad} \\ 0.1\,d_{lt,lr} & \text{for } \theta_{t,r} > 0.1\,d_{lt,lr} \quad \text{mrad} \end{cases} \tag{52a}$$

$A(p)$: time percentage variability (cumulative distribution):

$$A(p) = -12 + (1.2 + 3.7 \times 10^{-3} d) \log\left(\frac{p}{\beta}\right) + 12\left(\frac{p}{\beta}\right)^{\Gamma} \quad \text{dB} \tag{53}$$

$$\Gamma = \frac{1.076}{(2.0058 - \log\beta)^{1.012}} \times e^{-\left(9.51 - 4.8\log\beta + 0.198(\log\beta)^2\right) \times 10^{-6} \cdot d^{1.13}} \tag{53a}$$

$$\beta = \beta_0 \cdot \mu_2 \cdot \mu_3 \quad \% \tag{54}$$

μ_2: correction for path geometry:

$$\mu_2 = \left(\frac{500}{a_e} \frac{d^2}{\left(\sqrt{h_{te}} + \sqrt{h_{re}}\right)^2}\right)^{\alpha} \tag{55}$$

The value of μ_2 shall not exceed 1.

$$\alpha = -0.6 - \varepsilon \cdot 10^{-9} \cdot d^{3.1} \cdot \tau \tag{55a}$$

where:

ε: 3.5

τ: is defined in equation (3), and the value of α shall not be allowed to decrease below −3.4

μ_3: correction for terrain roughness:

$$\mu_3 = \begin{cases} 1 & \text{for } h_m \le 10 \text{ m} \\ e^{-4.6 \times 10^{-5} (h_m - 10)(43 + 6 d_I)} & \text{for } h_m > 10 \text{ m} \end{cases} \tag{56}$$

and:

$$d_I = \min(d - d_{lt} - d_{lr}, 40) \quad \text{km} \tag{56a}$$

The remaining terms have been defined in Tables 1 and 2 and Appendix 2 to this Annex.

4.6 Basic transmission loss not exceeded for *p*% time and 50% locations ignoring the effects of terminal clutter

The following procedure should be applied to the results of the foregoing calculations for all paths, in order to compute the basic transmission loss not exceeded for *p*% time and 50% locations. In order to avoid physically unreasonable discontinuities in the predicted notional basic transmission losses, the foregoing propagation models must be blended together to get modified values of basic transmission losses in order to achieve an overall prediction for *p*% time and 50% locations.

Calculate an interpolation factor, F_j, to take account of the path angular distance:

$$F_j = 1.0 - 0.5\left(1.0 + \tanh\left(3.0\,\xi \cdot \frac{(\theta - \Theta)}{\Theta}\right)\right) \tag{57}$$

where:

Θ : fixed parameter determining the angular range of the associated blending; set to 0.3

ξ : fixed parameter determining the blending slope at the end of the range; set to 0.8

θ : path angular distance (mrad) defined in Table 7.

Calculate an interpolation factor, F_k, to take account of the path great-circle distance:

$$F_k = 1.0 - 0.5\left(1.0 + \tanh\left(3.0\,\kappa \cdot \frac{(d - d_{sw})}{d_{sw}}\right)\right) \tag{58}$$

where:

d : great circle path length defined in Table 3 (km)

d_{sw} : fixed parameter determining the distance range of the associated blending; set to 20

κ : fixed parameter determining the blending slope at the ends of the range; set to 0.5.

Calculate a notional minimum basic transmission loss, L_{minb0p} (dB), associated with LoS propagation and over-sea sub-path diffraction:

$$L_{\min b0p} = \begin{cases} L_{b0p} + (1-\omega)L_{dp} & \text{for } p < \beta_0 \quad \text{dB} \\ L_{bd50} + (L_{b0\beta} + (1-\omega)L_{dp} - L_{bd50}) \cdot F_i & \text{for } p \geq \beta_0 \quad \text{dB} \end{cases} \tag{59}$$

where:

L_{b0p} : notional LoS basic transmission loss not exceeded for p% time, given by equation (10)

$L_{b0\beta}$: notional LoS basic transmission loss not exceeded for β_0% time, given by equation (11)

L_{dp} : diffraction loss not exceeded for p% time, given by equation (41)

L_{bd50} : median basic transmission loss associated with diffraction, given by equation (42)

F_i : Diffraction interpolation factor, given by equation (40).

Calculate a notional minimum basic transmission loss, L_{minbap} (dB), associated with LoS and transhorizon signal enhancements:

$$L_{minbap} = \eta \cdot \ln\left(e^{\left(\frac{L_{ba}}{\eta}\right)} + e^{\left(\frac{L_{b0p}}{\eta}\right)}\right) \quad \text{dB} \tag{60}$$

where:

L_{ba}: ducting/layer reflection basic transmission loss not exceeded for p% time, given by equation (46)

L_{b0p}: notional LoS basic transmission loss not exceeded for p% time, given by equation (10)

$\eta =$ 2.5.

Calculate a notional basic transmission loss, L_{bda} (dB), associated with diffraction and LoS or ducting/layer-reflection enhancements:

$$L_{bda} = \begin{cases} L_{bd} & \text{for } L_{minbap} > L_{bd} \\ L_{minbap} + (L_{bd} - L_{minbap}) \cdot F_k & \text{for } L_{minbap} \le L_{bd} \end{cases} \quad \text{dB} \tag{61}$$

where:

L_{bd}: basic transmission loss for diffraction not exceeded for p% time from equation (43)

L_{minbap}: notional minimum basic transmission loss associated with LoS propagation and trans-horizon signal enhancements from equation (60)

F_k: interpolation factor given by equation (58), according to the value of the path great-circle distance, d.

Calculate a modified basic transmission loss, L_{bam} (dB), which takes diffraction and LoS or ducting/layer-reflection enhancements into account:

$$L_{bam} = L_{bda} + (L_{minb0p} - L_{bda}) \cdot F_j \quad \text{dB} \tag{62}$$

where:

L_{bda}: notional basic transmission loss associated with diffraction and LoS or ducting/layer-reflection enhancements, given by equation (61)

L_{minb0p}: notional minimum basic transmission loss associated with LoS propagation and over-sea sub-path diffraction, given by equation (59)

F_j: interpolation factor given by equation (57), according to the value of the path angular distance, θ.

Calculate the basic transmission loss not exceeded for p% time and 50% locations ignoring the effects of terminal clutter, L_{bu} (dB), as given by:

$$L_{bu} = -5 \log\left(10^{-0.2 L_{bs}} + 10^{-0.2 L_{bam}}\right) \quad \text{dB} \tag{63}$$

where:

L_{bs}: basic transmission loss due to troposcatter not exceeded for p% time, given by equation (44)

L_{bam}: modified basic transmission loss taking diffraction and LoS ducting/layer-reflection enhancements into account, given by equation (62).

4.7 Additional losses due to terminal surroundings

When the transmitter or receiver antenna is located below the height R_t or R_r representative of ground cover surrounding the transmitter or receiver, estimates of the additional losses, A_{ht}, A_{hr}, are calculated as follows. Appropriate values for R are discussed in § 3.2.

The method given below gives the median of losses due to different terminal surroundings. The possible mechanisms include obstruction loss and reflections due to clutter objects at the representative height, and scattering and reflection from the ground and smaller clutter objects. When using a computer implementation, with terrain profile extracted from a digital terrain model, and with the terminal surroundings defined by a clutter category, it is not practicable to identify individual mechanisms. The method used here distinguishes between two general cases: for woodland and urban categories it is assumed that the dominant mechanism is diffraction over clutter; for other categories it is assumed that reflection or scattering dominates.

The method for transmitter and receiver is identical, and in the following, $A_h = A_{ht}$ or A_{hr}, $h = h_{tg}$ or h_{rg} and $R = R_t$ or R_r as appropriate.

If $h \geq R$ then $A_h = 0$

If $h < R$, then A_h can take one of two forms, depending on clutter type (see Table 2):

$$A_h = J(\nu) - 6.03 \qquad \text{dB} \tag{64a}$$

or:

$$A_h = -K_{h2} \log(h/R) \qquad \text{dB} \tag{64b}$$

$J(\nu)$ is calculated using equation (12).

The terms ν and K_{h2} are given by:

$$\nu = K_{nu} \sqrt{h_{dif}\ \theta_{clut}} \tag{64c}$$

$$h_{dif} = R - h \qquad \text{m} \tag{64d}$$

$$\theta_{clut} = \tan^{-1}(h_{dif} / 27) \qquad \text{degrees} \tag{64e}$$

$$K_{h2} = 21.8 + 6.2 \log(f) \tag{64f}$$

$$K_{nu} = 0.342 \sqrt{f} \tag{64g}$$

where:

f: frequency (GHz).

The form of equation (64a) represents Fresnel diffraction loss over an obstacle and would be applied to clutter categories such as buildings. In particular urban clutter would be of this type.

Equation (64b) represents the height gain function due to the proximity of the ground in more open locations. Where specular ground reflection occurs this is typical of signal variations below the first two-ray interference maximum. Where specular reflection does not occur the variations below R are typical of those due to shadowing by minor objects and irregularities.

A clearly-defined first two-ray maximum occurs only under special conditions permitting ground reflection, and cannot be identified from the usual topographic data available for computer systems. Unless special information is available on the surrounding of a terminal, the value of R associated with the clutter category should be used in equation (64b).

If special information is available which identifies a flat, smooth reflecting surface with adequate Fresnel clearance to support ground reflection, then R can be calculated using the method given in Appendix 4. However, this approach attempts to identify a specific point on the multipath distribution, which is not consistent with the principles underlying point-to-area prediction, and is incompatible with the location-variability calculation given in § 4.8. The detailed estimation of ground reflection should thus be restricted to the use of the Recommendation other than for point-to-area prediction.

The basic transmission loss not exceeded for p% time and 50% locations, including the effects of terminal clutter losses, L_{bc} (dB), is given by:

$$L_{bc} = L_{bu} + A_{ht} + A_{hr} \qquad \text{dB} \tag{65}$$

where:

L_{bu} : the basic transmission loss not exceeded for p% time and 50% locations at (or above, as appropriate) the height of representative clutter, given by equation (63)

$A_{ht,hr}$: the additional losses to account for terminal surroundings, equations (64a and 64b) as appropriate.

4.8 Location variability of losses

In this Recommendation, and generally, location variability refers to the spatial statistics of local ground cover variations. This is a useful result over scales substantially larger than the ground cover variations, and over which path variations are insignificant. As location variability is defined to exclude multipath variations, it is independent of system bandwidth.

In the planning of radio systems, it will also be necessary to take multipath effects into account. The impact of these effects will vary with systems, being dependent on bandwidths, modulations and coding schemes. Guidance on the modelling of these effects is given in Recommendation ITU-R P.1406.

Extensive data analysis suggests that the distribution of median field strength due to ground cover variations over such an area in urban and suburban environments is approximately lognormal with zero mean.

Values of the standard deviation are dependent on frequency and environment, and empirical studies have shown a considerable spread. Representative values for areas of 500 × 500 m are given by the following expression:

$$\sigma_L = K + 1.3 \log(f) \qquad \text{dB} \tag{66}$$

where:

$K =$ 5.1, for receivers with antennas below clutter height in urban or suburban environments for mobile systems with omnidirectional antennas at car-roof height

$K =$ 4.9 for receivers with rooftop antennas near the clutter height

$K =$ 4.4 for receivers in rural areas

f : required frequency (GHz).

If the area over which the variability is to apply is greater than 500 × 500 m, or if the variability is to relate to all areas at a given range, rather than the variation across individual areas, the value of σ_L will be greater. Empirical studies have suggested that location variability is increased (with respect to the small area values) by up to 4 dB for a 2 km radius and up to 8 dB for a 50 km radius.

The percentage locations, p_L, can vary between 1% and 99%. This model is not valid for percentage locations less than 1% or greater than 99%.

It should be noted that, for some planning purposes (e.g. multilateral allotment plans) it will generally be necessary to use a definition of "location variability" that includes a degree of multipath fading. This will allow for the case of a mobile receiver, stationary in a multipath null, or for a rooftop antenna where a number of frequencies are to be received and the antenna cannot be optimally positioned for all. Additionally, such planning may also need to consider variability over a greater area than that assumed in this Recommendation.

In this context, the values given in Table 5 have been found appropriate for the planning of a number of radio services.

TABLE 5

Values of location variability standard deviations used in certain planning situations

	Standard deviation		
	100 MHz	**600 MHz**	**2 000 MHz**
Broadcasting, analogue (dB)	8.3	9.5	–
Broadcasting, digital (dB)	5.5	5.5	5.5

The location variability correction should not be applied when the receiver/mobile is adjacent to the sea.

When the receiver/mobile is located on land and outdoors but its height above ground is greater than or equal to the height of representative clutter, it is reasonable to expect that the location variability will decrease monotonically with increasing height until, at some point, it vanishes. In this Recommendation, the location variability height variation, $u(h)$, is given by:

$$\begin{aligned} u(h) &= 1 && \text{for} \quad 0 \le h < R \\ u(h) &= 1 - \frac{(h-R)}{10} && \text{for} \quad R \le h < R+10 \\ u(h) &= 0 && \text{for} \quad R+10 \le h \end{aligned} \tag{67}$$

where R (m) is the height of representative clutter at the receiver/mobile location. Therefore, for a receiver/mobile located outdoors, the standard deviation of the location variability, σ_L, as given by either equation (66) or Table 5, should be multiplied by the height variation function, $u(h)$, given in equation (67), when computing values of the basic transmission loss for values of p_L% different from 50%.

4.9 Building entry loss

Building entry loss is defined as the difference (dB) between the mean field strength (with respect to locations) outside a building at a given height above ground level and the mean field strength inside the same building (with respect to locations) at the same height above ground level.

For *indoor reception* two important parameters must also be taken into account. The first is the building entry loss and the second is the variation of the building entry loss due to different building materials. The standard deviations, given below, take into account the large spread of building entry losses but do not include the location variability within different buildings. It should be noted that there is limited reliable information and measurement results about building entry loss. Provisionally, building entry loss values that may be used are given in Table 6.

TABLE 6

Building entry loss[1], L_{be}, σ_{be}

F	**Median value, L_{be} (dB)**	**Standard deviation, σ_{be} (dB)**
0.2 GHz	9	3
0.6 GHz	11	6
1.5 GHz	11	6

(1) These values may have to be updated when more experimental data become available.

For frequencies below 0.2 GHz, L_{be} = 9 dB, σ_{be} = 3 dB; for frequencies above 1.5 GHz, L_{be} = 11 dB, σ_{be} = 6 dB. Between 0.2 GHz and 0.6 GHz (and between 0.6 GHz and 1.5 GHz), appropriate values for L_{be} and σ_{be} can be obtained by linear interpolation between the values for L_{be} and σ_{be} given in the Table for 0.2 GHz and 0.6 GHz (0.6 GHz and 1.5 GHz).

The field-strength variation for indoor reception is the combined result of the outdoor variation, σ_L, and the variation due to building attenuation, σ_{be}. These variations are likely to be uncorrelated. The standard deviation for indoor reception, σ_i can therefore be calculated by taking the square root of the sum of the squares of the individual standard deviations.

$$\sigma_i = \sqrt{\sigma_L^2 + \sigma_{be}^2} \tag{68}$$

where σ_L is the standard deviation of location variability, as given by equation (66) or Table 5.

For example, for digital emissions with bandwidth greater than 1 MHz, at VHF, where the signal standard deviations are 5.5 dB and 3 dB respectively, the combined value is 6.3 dB. In Band IV/V, where the signal standard deviations are 5.5 dB and 6 dB, the combined value is 8.1 dB.

4.10 Basic transmission loss not exceeded for *p*% time and p_L% locations

In order to compute the desired percentage locations, the median loss, L_{loc}, and the standard deviation, σ_{loc}, are given by:

$$L_{loc} = 0 \quad \text{(outdoors)} \tag{69a}$$

$$L_{loc} = L_{be} \quad \text{(indoors)} \tag{69b}$$

and:

$$\sigma_{loc} = u(h) \cdot \sigma_L \quad \text{(outdoors)} \tag{70a}$$

$$\sigma_{loc} = \sigma_i \quad \text{(indoors)} \tag{70b}$$

where the median building entry loss, L_{be}, is given in Table 6, the height function, $u(h)$, is given by equation (67) and the standard deviations, σ_L and σ_i, are given by equation (66) (or Table 5) and equation (68), respectively.

The basic transmission loss not exceeded for *p*% time and p_L% locations, L_b (dB), is given by:

$$L_b = \max\left\{L_{b0p}, L_{bc} + L_{loc} - I\left(\frac{p_L}{100}\right) \cdot \sigma_{loc}\right\} \quad \text{dB} \tag{71}$$

where:

L_{b0p} : basic transmission loss not exceeded for p% time and 50% locations associated with LoS with short term enhancements, given by equation (10)

L_{bc} : basic transmission loss not exceeded for p% of time and 50% locations, including the effects of terminal clutter losses, given by equation (65)

L_{loc} : median value of the location loss, as given by equations (69a) and (69b)

$I(x)$: inverse complementary cumulative normal distribution as a function of probability, x. An approximation for $I(x)$ which may be used for $0.000001 \le x \le 0.999999$ is given in Appendix 3 to this Annex

σ_{loc} : combined standard deviation (i.e. building entry loss and location variability), given by equations (70a) and (70b).

The percentage locations, p_L, can vary between 1% and 99%. This model is not valid for percentage locations less than 1% or greater than 99%.

4.11 The field strength exceeded for *p*% time and p_L% locations

The field strength normalized to 1 kW effective radiated power exceeded for p% time and 50% locations, E_p dB(µV/m), may be calculated using:

$$E_p = 199.36 + 20\log(f) - L_b \qquad \text{dB(µV/m)} \tag{72}$$

where:

L_b: basic transmission loss not exceeded for p% time and p_L% locations calculated by equation (71)

f: required frequency (GHz).

Appendix 1
to Annex 1

Radio-meteorological data required for the prediction procedure

Figure 1 gives average annual values of ΔN as positive values in N-units/km.

FIGURE 1

Average annual values of ΔN, N-units/km

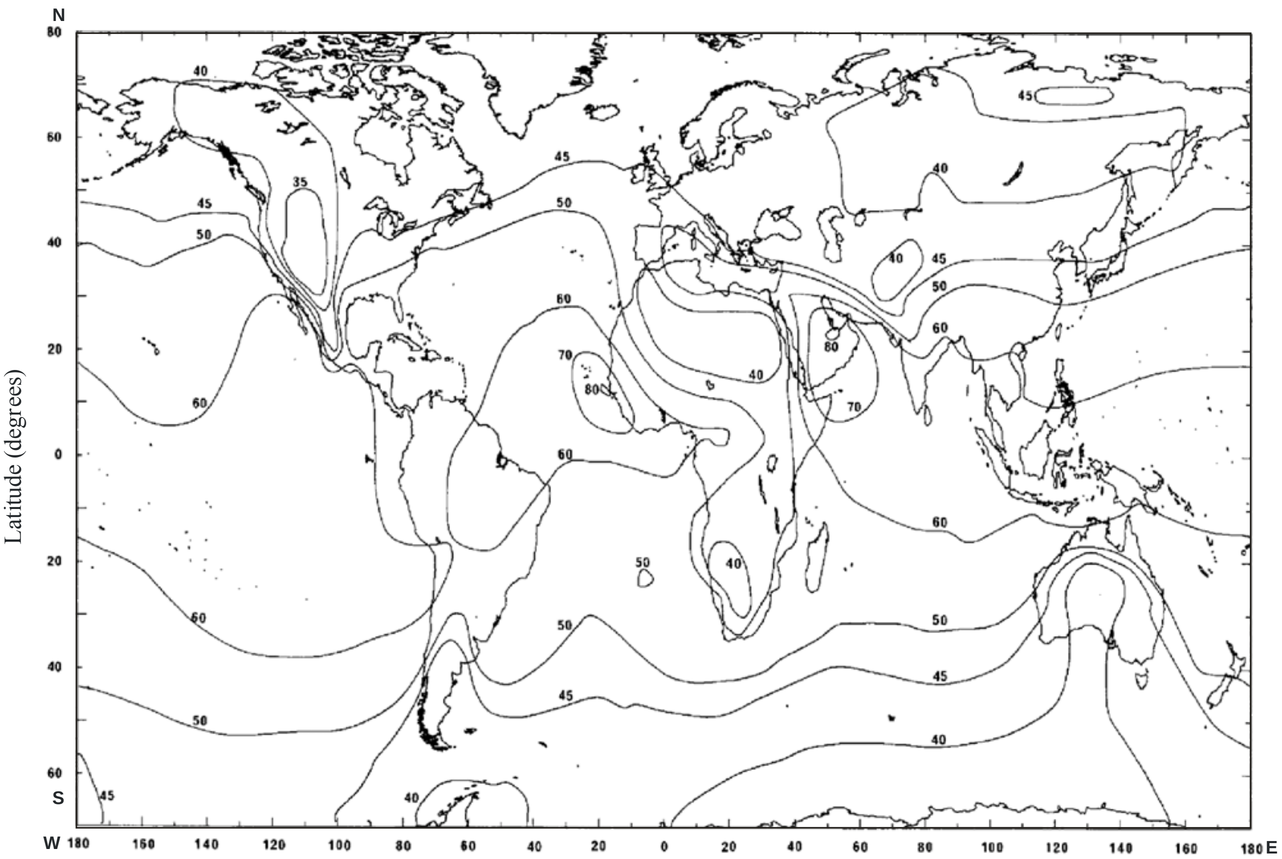

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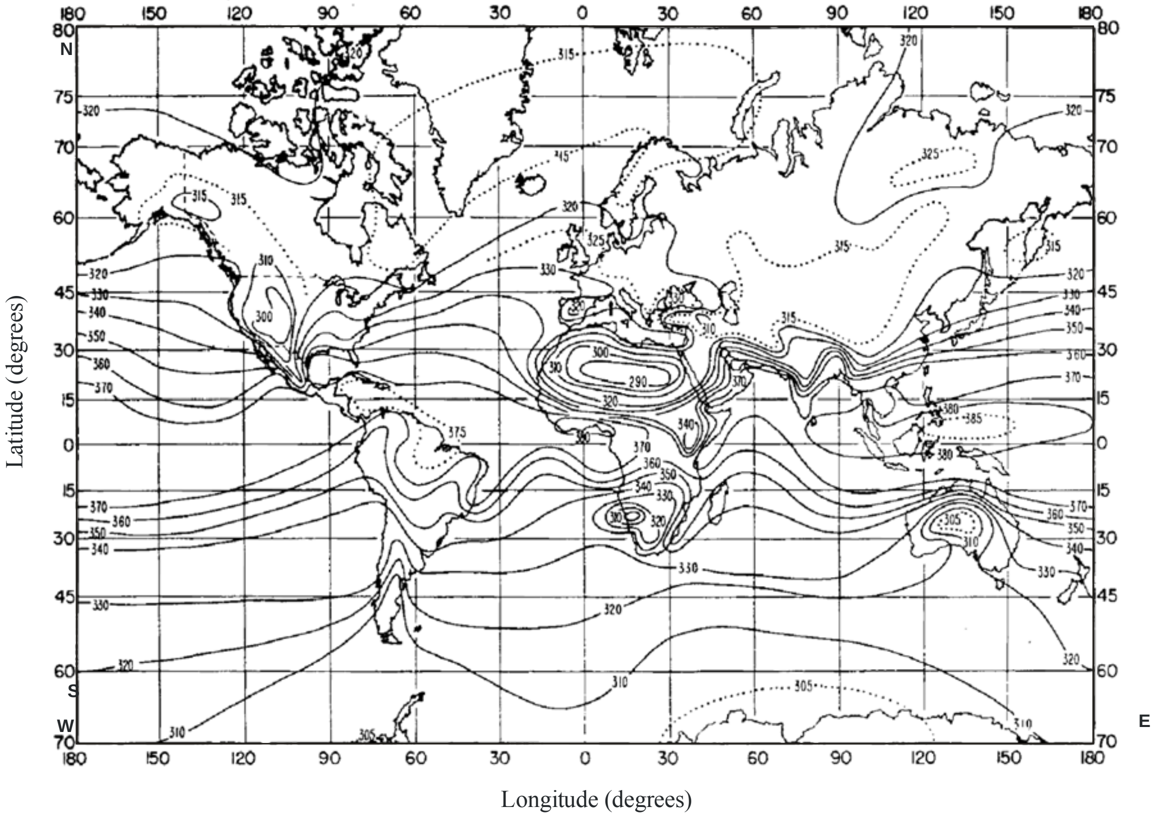
Figure 2 gives average annual values of sea-level surface refractivity, N_0, in N-units. Parameter N_0 is used only in the tropospheric-scatter part of the overall method.

FIGURE 2

Sea-level surface refractivity, N-units



Appendix 2
to Annex 1

Path profile analysis

1 Introduction

For path profile analysis, a path profile of terrain heights above mean sea level is required. The parameters that need to be derived from the path profile analysis for the purposes of the propagation models are given in Table 7.

2 Construction of path profile

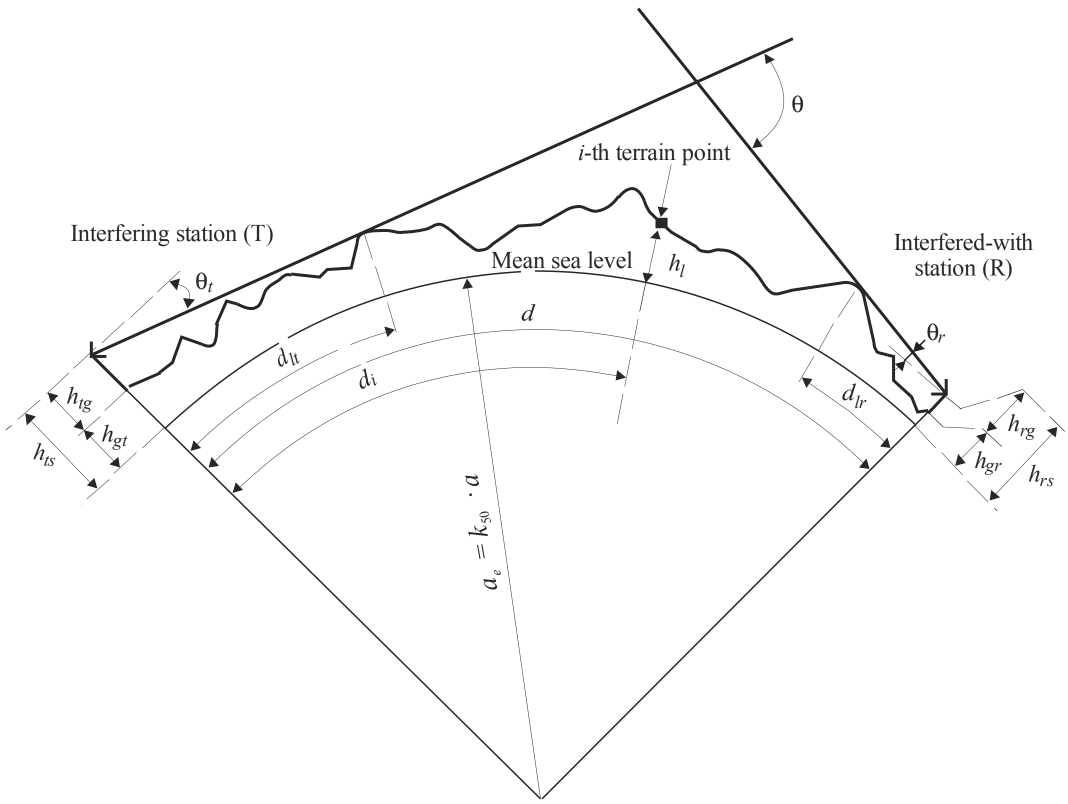
Based on the geographical coordinates of the transmitting (φ_t, ψ_t) and receiving (φ_r, ψ_r) stations, terrain heights (above mean sea level) along the great-circle path should be derived from a topographical database or from appropriate large-scale contour maps. The distance resolution of the profile should be as far as is practicable to capture significant features of the terrain. Typically, a distance increment of 30 m to 1 km is appropriate. In general, it is appropriate to use longer distance increments for longer paths. The profile should include the ground heights at the transmitting and receiving station locations as the start and end points. The equations of this section take Earth curvature into account where necessary, based on the value of a_e found in equation (7a).

Although equally spaced profile points are considered preferable, it is possible to use the method with non-equally spaced profile points. This may be useful when the profile is obtained from a digital map of terrain height contours. However, it should be noted that the Recommendation has been developed from testing using equally spaced profile points; information is not available on the effect of non-equally spaced points on accuracy.

For the purposes of this Recommendation the point of the path profile at the transmitting station is considered as point 1, and the point at the receiving station is considered as point n. The path profile therefore consists of n points. Figure 3 gives an example of a path profile of terrain heights above mean sea level, showing the various parameters related to the actual terrain.

FIGURE 3

Example of a (trans-horizon) path profile



Note 1 – The value of θ_t as drawn will be negative.

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Table 7 defines parameters used or derived during the path profile analysis.

TABLE 7

Path profile parameter definitions

Parameter	Description
a_e	Effective Earth's radius (km)
d	Great-circle path distance (km)
d_{ii}	Incremental distance for regular (i.e. equally spaced) path profile data (km)
f	Frequency (GHz)
λ	Wavelength (m)
h_{ts}	Transmitter antenna height (m) above mean sea level (amsl)
h_{rs}	Receiver antenna height (m) (amsl)
θ_t	For a trans-horizon path, horizon elevation angle above local horizontal (mrad), measured from the transmitting antenna. For a LoS path this should be the elevation angle of the receiving antenna
θ_r	For a trans-horizon path, horizon elevation angle above local horizontal (mrad), measured from the receiving antenna. For a LoS path this should be the elevation angle of the transmitting antenna
θ	Path angular distance (mrad)
h_{st}	Height of the smooth-Earth surface (amsl) at the transmitting station location (m)
h_{sr}	Height of the smooth-Earth surface (amsl) at the receiving station location (m)
h_i	Height of the i-th terrain point amsl (m) h_1 : ground height of the transmitter h_n : ground height of receiver
h_m	Terrain roughness (m)
h_{te}	Effective height of transmitting antenna (m)
h_{re}	Effective height of receiving antenna (m)

3 Path length

The path length can be obtained using great-circle geometry from the geographical coordinates of the transmitting (φ_t, ψ_t) and receiving (φ_r, ψ_r) stations. Alternatively the path length can be found from the path profile. The path length, d (km), can be found from the path profile data:

$$d = d_n \qquad \text{km} \tag{73}$$

For regularly spaced path profile data it is also true that:

$$d_i = (i-1) \cdot d_{ii} \qquad \text{km} \tag{74}$$

for $i = 1, \ldots, n$, where d_{ii} is the incremental path distance (km).

4 Path classification

The path profile must be used to determine whether the path is LoS or trans-horizon based on the median effective Earth's radius of a_e, as given by equation (7a).

A path is trans-horizon if the physical horizon elevation angle as seen by the transmitting antenna (relative to the local horizontal) is greater than the angle (again relative to the transmitter's local horizontal) subtended by the receiving antenna.

The test for the trans-horizon path condition is thus:

$$\theta_{max} > \theta_{td} \qquad \text{mrad} \tag{75}$$

where:

$$\theta_{max} = \max_{i=2}^{n-1} (\theta_i) \qquad \text{mrad} \tag{76}$$

θ_i: elevation angle to the i-th terrain point

$$\theta_i = \frac{h_i - h_{ts}}{d_i} - \frac{10^3 \, d_i}{2 \, a_e} \qquad \text{mrad} \tag{77}$$

where:

h_i: height of the i-th terrain point amsl (m)

h_{ts}: transmitter antenna height amsl (m)

d_i: distance from transmitter to the i-th terrain element (km)

$$\theta_{td} = \frac{h_{rs} - h_{ts}}{d} - \frac{10^3 \, d}{2 \, a_e} \qquad \text{mrad} \tag{78}$$

where:

h_{rs}: receiving antenna height amsl (m)

d: total great-circle path distance (km)

a_e: median effective Earth's radius appropriate to the path (see equation (7a)).

5 Derivation of parameters from the path profile

5.1 All paths

The parameters to be derived from the path profile are those contained in Table 7.

5.1.1 Transmitting antenna horizon elevation angle above the local horizontal, θ_t

The transmitting antenna's horizon elevation angle relative to the local horizontal is given by:

$$\theta_t = \max(\theta_{max}, \theta_{td}) \qquad \text{mrad} \tag{79}$$

with θ_{max} as determined in equation (76). Thus for a LoS path the transmitting antenna's horizon elevation angle is considered to be the elevation angle of the line to the receiving antenna.

5.1.2 Transmitting antenna horizon distance, d_{lt}

The horizon distance is the minimum distance from the transmitter at which the maximum antenna horizon elevation angle is calculated from equation (76).

$$d_{lt} = d_i \qquad \text{km} \qquad \text{for max } (\theta_i) \tag{80}$$

For a LoS path, the index *i* should be the value which gives the maximum diffraction parameter ν in equation (15).

5.1.3 Receiving antenna horizon elevation angle above the local horizontal, θ_r

For a LoS path, θ_r is given by:

$$\theta_r = \frac{h_{ts} - h_{rs}}{d} - 10^3 \frac{d}{2a_e} \qquad \text{mrad} \tag{81}$$

Otherwise, θ_r is given by:

$$\theta_r = \max_{j=2}^{n-1} (\theta_j) \qquad \text{mrad} \tag{82}$$

$$\theta_j = \frac{h_j - h_{rs}}{d - d_j} - \frac{10^3 \, (d - d_j)}{2 \, a_e} \qquad \text{mrad} \tag{82a}$$

5.1.4 Receiving antenna horizon distance, d_{lr}

The horizon distance is the minimum distance from the receiver at which the maximum antenna horizon elevation angle is calculated from equation (82).

$$d_{lr} = d - d_j \qquad \text{km} \qquad \text{for max } (\theta_j) \tag{83}$$

For a LoS path, θr is given by:

$$d_{lr} = d - d_{lt} \qquad \text{km} \tag{83a}$$

5.1.5 Angular distance θ (mrad)

$$\theta = \frac{10^3 \, d}{a_e} + \theta_t + \theta_r \qquad \text{mrad} \tag{84}$$

5.1.6 "Smooth-Earth" model and effective antenna heights

5.1.6.1 General

A "smooth-Earth" surface is derived from the profile to calculate effective antenna heights both for the diffraction model, and for an assessment of path roughness required by the ducting/layer-reflection model. The definitions of effective antenna heights differ for these two purposes. Sub-section § 5.1.6.2 describes the derivation of uncorrected smooth-earth surface heights at the transmitter and receiver, h_{st} and h_{sr} respectively. Sub-sections § 5.1.6.3 and § 5.1.6.4 then describe the derivation of effective antenna heights for the diffraction model, h_{ted} and h_{red}, and the calculation of the terrain roughness parameter, h_m, respectively.

5.1.6.2 Deriving the smooth-Earth surface

Derive a straight line approximation to the terrain heights amsl of the form:

$$h_{si} = h_{st} + m \cdot d_i \qquad \text{m} \tag{85}$$

where:

- h_{si} : height amsl (m), of the least-squares fit surface at distance d_i (km) from the transmitter
- h_{st} : height amsl (m), of the smooth-Earth surface at the path origin, i.e. at the transmitter
- m : slope of the least-squares surface relative to sea level (m/km).

Alternative methods are available for the next two steps in the calculation. Equations (86a) and (87a) may be used if the profile points are equally spaced. Equations (86b) and (87b), which are more complicated, must be used if the profile points are not equally spaced, and may be used in either case.

For equally spaced profiles:

$$m = \frac{\sum_{i=1}^{n} (h_i - h_a)\left(d_i - \frac{d}{2}\right)}{\sum_{i=1}^{n}\left(d_i - \frac{d}{2}\right)^2} \qquad \text{m/km} \tag{86a}$$

For any profile:

$$m = \left(\frac{1}{d^3}\right)\sum_{i=2}^{n} 3\,(d_i - d_{i-1})\,(d_i + d_{i-1} - d)\,(h_i + h_{i-1} - 2h_a) + (d_i - d_{i-1})^2\,(h_i - h_{i-1}) \qquad \text{m/km} \tag{86b}$$

where:

- h_i : real height of the i-th terrain point amsl (m)
- h_a : mean of the real path heights amsl from h_0 to h_n inclusive (m) given by:

For equally spaced profiles:

$$h_a = \frac{1}{n}\sum_{i=1}^{n} h_i \qquad \text{m} \tag{87a}$$

For any profile a weighted mean is calculated:

$$h_a = \left(\frac{1}{2d}\right)\sum_{i=2}^{n}(d_i - d_{i-1})\,(h_i + h_{i-1}) \qquad \text{m} \tag{87b}$$

The height of the smooth-Earth surface at the transmitting station, h_{st}, is then given by:

$$h_{st} = h_a - m\frac{d}{2} \qquad \text{m} \tag{88}$$

and hence the height of the smooth-Earth surface at the receiving station, h_{sr}, is given by:

$$h_{sr} = h_{st} + m \cdot d \qquad \text{m} \tag{89}$$

5.1.6.3 Effective antenna heights for the diffraction model

Find the highest obstruction height above the straight-line path from transmitter to receiver h_{obs}, and the horizon elevation angles α_{obt}, α_{obr}, all based on flat-Earth geometry, according to:

$$h_{obs} = \max\{h_{obi}\} \qquad \text{m} \tag{90a}$$

$$\alpha_{obt} = \max\{h_{obi} / d_i\} \qquad \text{mrad} \tag{90b}$$

$$\alpha_{obr} = \max\{h_{obi} / (d - d_i)\} \qquad \text{mrad} \tag{90c}$$

where:

$$h_{obi} = h_i - [h_{ts}(d - d_i) + h_{rs} d_i] / d \qquad \text{m} \tag{90d}$$

and the profile index i takes values from 2 to (n-1).

Calculate provisional values for the heights of the smooth surface at the transmitter and receiver ends of the path:

If h_{obs} is less than or equal to zero, then:

$$h_{stp} = h_{st} \quad \text{masl} \tag{91a}$$

$$h_{srp} = h_{sr} \quad \text{masl} \tag{91b}$$

otherwise:

$$h_{stp} = h_{st} - h_{obs} g_t \quad \text{masl} \tag{91c}$$

$$h_{srp} = h_{sr} - h_{obs} g_r \quad \text{masl} \tag{91d}$$

where:

$$g_t = \alpha_{obt} / (\alpha_{obt} + \alpha_{obr}) \tag{91e}$$

$$g_r = \alpha_{obr} / (\alpha_{obt} + \alpha_{obr}) \tag{91f}$$

Calculate final values for the heights of the smooth surface at the transmitter and receiver ends of the path as required by the diffraction model:

If h_{stp} is greater than h_1 then:

$$h_{std} = h_1 \quad \text{masl} \tag{92a}$$

otherwise:

$$h_{std} = h_{stp} \quad \text{masl} \tag{92b}$$

If h_{srp} is greater than h_n then:

$$h_{srd} = h_n \quad \text{masl} \tag{92c}$$

otherwise:

$$h_{srd} = h_{srp} \quad \text{masl} \tag{92d}$$

5.1.6.4 Parameters for the ducting/layer-reflection model

Calculate the smooth-Earth heights at transmitter and receiver as required for the roughness factor given by:

$$h_{st} = \min\ (h_{st}, h_1) \qquad \text{m} \tag{93a}$$

$$h_{sr} = \min\ (h_{sr}, h_n) \qquad \text{m} \tag{93b}$$

If either or both of h_{st} or h_{sr} were modified by equations (93a) or (93b) then the slope, m, of the smooth-Earth surface must also be corrected:

$$m = \frac{h_{sr} - h_{st}}{d} \qquad \text{m/km} \tag{94}$$

The terminal effective heights for the ducting/layer-reflection model, h_{te} and h_{re}, are given by:

$$\begin{aligned} h_{te} &= h_{tg} + h_1 - h_{st} \qquad \text{m} \\ h_{re} &= h_{rg} + h_n - h_{sr} \qquad \text{m} \end{aligned} \tag{95}$$

The terrain roughness parameter, h_m (m) is the maximum height of the terrain above the smooth-Earth surface in the section of the path between, and including, the horizon points:

$$h_m = \max_{i = i_{lt}}^{i_{lr}} \left[h_i - (h_{st} + m \cdot d_i) \right] \qquad \text{m} \tag{96}$$

where:

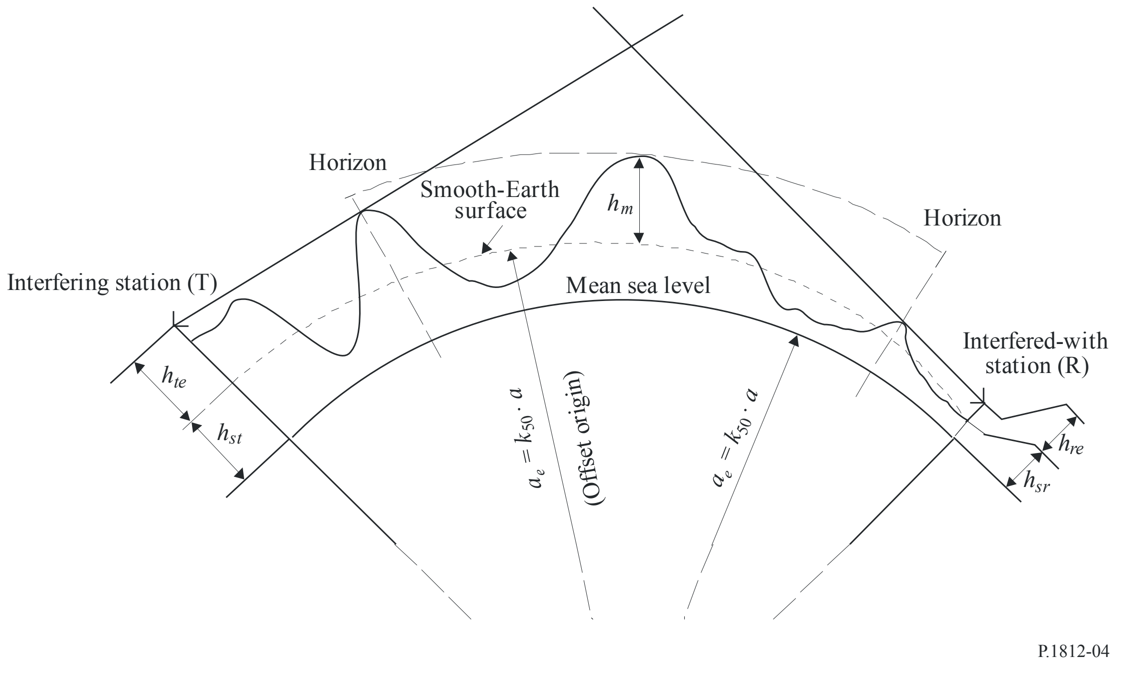
i_{lt}: index of the profile point at distance d_{lt} from the transmitter

i_{lr}: index of the profile point at distance d_{lr} from the receiver.

The smooth-Earth surface and the terrain roughness parameter h_m are illustrated in Fig. 4.

FIGURE 4

An example of the smooth-Earth surface and terrain roughness parameter



Appendix 3
to Annex 1

An approximation to the inverse complementary cumulative normal distribution function

The following approximation to the inverse complementary cumulative normal distribution function is valid for $0.000001 \le x \le 0.999999$ and is in error by a maximum of 0.00054. If $x < 0.000001$, which implies $\beta_0 < 0.0001\%$, x should be set to 0.000001. Similar considerations hold for $x > 0.999999$. This approximation may be used with confidence for the interpolation function in equations (30b) and (49) and in equation (61). For the latter equation, however, the value of x must be limited: $0.01 \le x \le 0.99$.

The function $I(x)$ is given by:

$$I(x) = T(x) - \xi(x) \qquad \text{for } 0.000001 \le x \le 0.5 \tag{97a}$$

and, by symmetry:

$$I(x) = \xi(1-x) - T(1-x) \qquad \text{for } 0.5 < x \le 0.999999 \tag{97b}$$

where:

$$T(x) = \sqrt{[-2\ \ln(x)]} \tag{98a}$$

$$\xi(x) = \frac{[(C_2 \cdot T(x) + C_1) \cdot T(x)] + C_0}{[(D_3 \cdot T(x) + D_2)\, T(x) + D_1]\, T(x) + 1} \tag{98b}$$

$$C_0 = 2.515516698 \tag{98c}$$

$$C_1 = 0.802853 \tag{98d}$$

$$C_2 = 0.010328 \tag{98e}$$

$$D_1 = 1.432788 \tag{98f}$$

$$D_2 = 0.189269 \tag{98g}$$

$$D_3 = 0.001308 \tag{98h}$$

Appendix 4
to Annex 1

Criteria for ground reflection and calculation of first reflection maximum

This appendix gives criteria for identifying situations which support two-ray ground reflection. The path information required would normally require detailed inspection of a terminal's surroundings, or the use of high-resolution topographic data with resolution and accuracy better than of the order of 1 metre. If the criteria are satisfied the height of the first two-ray maximum can be calculated. Because this represents a specific point on the multipath signal-level distribution, this method should not be used with the location-variability calculation described in § 4.8 of the Recommendation, and is not suitable for point-to-area calculations.

FIGURE 5

Required geometry for ground reflections

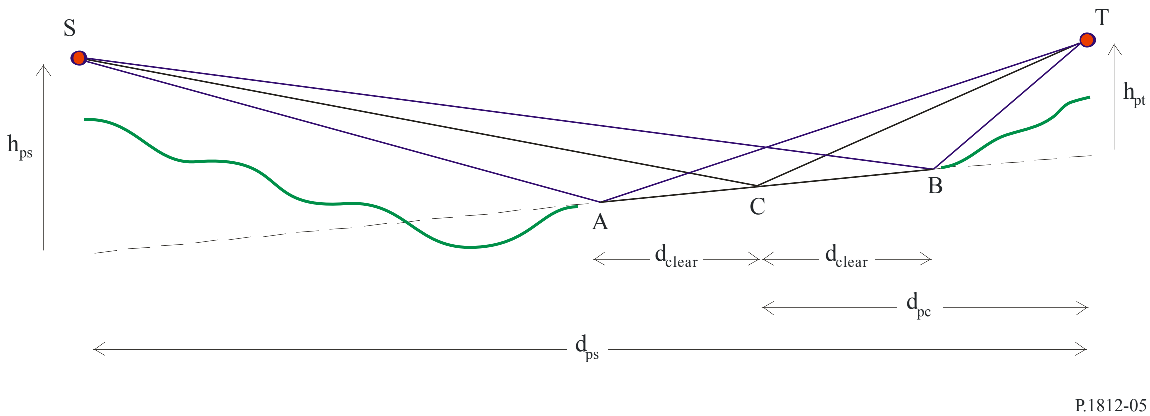


Figure 5 illustrates the geometry required for ground reflection. Point 'T' on the right is the terminal under consideration. Point 'S' is the reflection source point, which will be the other terminal for a LoS path, or the radio horizon of T for a transhorizon path.

A notional profile is indicated by the curving green line. A section of the profile between points A and B must be identified as flat and smooth, and there must be LoS with full Fresnel clearance for the lines S-A, S-B, A-T and B-T.

Self-consistent units are used throughout this appendix.

Point C is the specular reflection point at the centre of line A-B, with distance d_{cp} from the terminal given by:

$$d_{pc} = d_{ps} h_{ps} / \left(h_{ps} + h_{pt}\right) \tag{99}$$

where h_{ps} and h_{pt} are the heights of S and T respectively above line A-B extended.

The required Fresnel clearance radius r_{clear} at C is given by:

$$r_{clear} = 0.6 \sqrt{\lambda d_{pc} \left(d_{ps} - d_{pc}\right) / d_{ps}} \tag{100}$$

where λ is the wavelength.

The reflecting surface should be flat and smooth and have LoS to both S and T for an area up to r_{clear} to each side of the path (that is, to left and to right) from T to the other terminal.

The required clearance distance d_{clear} each side of C in line with the radio path is approximated by:

$$d_{clear} \approx r_{clear} d_{pc} / h_{pt} \qquad (101)$$

A criterion for the flatness and smoothness of the reflecting surface is given by:

$$\Delta \approx \frac{\lambda d_{pc}}{10 h_{pt}} \qquad (102)$$

where Δ is the allowable departure of the reflection surface from a plane. This should be interpreted on a small scale in terms of roughness, and over the whole area in terms of flatness.

If the above criteria are satisfied, the value of R in equation (64b) can be calculated by:

$$R = \frac{\lambda d_{ps}}{4 h_{pt}} \qquad (103)$$

If the value of R calculated using equation (103) is used in equation (64b), as terminal height decreases below R an increasingly good approximation is given to the plane-earth two-ray model for grazing-incidence reflection. As terminal height decreases the flat smooth reflecting surface shown in Fig. 5 is required to be extended towards the terminal, equivalent to point B in the figure moving to the right.

The height gain correction may also be calculated using explicit two-ray summation, which gives:

$$A_h = 20 \log \left[1 + \rho \exp \left(-j \frac{2\pi\delta}{\lambda} \right) \right] \qquad (104)$$

where:

- ρ : complex reflection coefficient, which for grazing incidence can be estimated as a pure number with approximate value –0.95
- δ : is the path-length difference given by:

$$\delta = \frac{2 h_{ps} h_{pt}}{d_{ps}} \qquad (105)$$

If equation (104) is used the value of A_h will be +6 dB at $h_{pt} = R$. There will be a discontinuity with equation (64b) at this point. As h_{pt} is reduced from R equation (104) will increasingly approximate to equation (64b). If equation (104) is used below R then the warning above concerning the extent of the reflecting surface should be noted. If equation (104) is used above R the reflecting surface must exist at a corresponding greater distance from the terminal, and account should also be taken of the possibility that the source distance d_s might increase, that is the position of S in Fig. 5 might change. This latter issue can be avoided if the reflection method is used only for a LoS path.