



Recommendation ITU-R P.618-13
(12/2017)

**Propagation data and prediction methods
required for the design of Earth-space
telecommunication systems**

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.618-13

Propagation data and prediction methods required for the design of Earth-space telecommunication systems

(Question ITU-R 206/3)

(1986-1990-1992-1994-1995-1997-1999-2001-2003-2007-2009-2013-2015-2017)

Scope

This Recommendation predicts the various propagation parameters needed in planning Earth-space systems operating in either the Earth-to-space or space-to-Earth direction.

The ITU Radiocommunication Assembly,

considering

- a) that for the proper planning of Earth-space systems, it is necessary to have appropriate propagation data and prediction techniques;
- b) that methods have been developed that allow the prediction of the most important propagation parameters needed in planning Earth-space systems;
- c) that as far as possible, these methods have been tested against available data and have been shown to yield an accuracy that is both compatible with the natural variability of propagation phenomena and adequate for most present applications in system planning,

recommends

that the methods for predicting the propagation parameters set out in Annex 1 should be adopted for planning Earth-space radiocommunication systems, in the respective ranges of validity indicated in Annex 1.

NOTE – Supplementary information related to the planning of broadcasting-satellite systems as well as maritime, land, and aeronautical mobile-satellite systems, may be found in Recommendations ITU-R P.679, ITU-R P.680, ITU-R P.681 and ITU-R P.682, respectively.

Annex 1**1 Introduction**

In the design of Earth-space links for communication systems, several effects must be considered. Effects of the non-ionized atmosphere need to be considered at all frequencies, but become critical above about 1 GHz and for low elevation angles. These effects include:

- a) absorption in atmospheric gases; absorption, scattering and depolarization by hydrometeors (water and ice droplets in precipitation, clouds, etc.); and emission noise from absorbing media; all of which are especially important at frequencies above about 10 GHz;
- b) loss of signal due to beam-divergence of the earth-station antenna, due to the normal refraction in the atmosphere;

- c) a decrease in effective antenna gain, due to phase decorrelation across the antenna aperture, caused by irregularities in the refractive-index structure;
- d) relatively slow fading due to beam-bending caused by large-scale changes in refractive index; more rapid fading (scintillation) and variations in angle of arrival, due to small-scale variations in refractive index;
- e) possible limitations in bandwidth due to multiple scattering or multipath effects, especially in high-capacity digital systems;
- f) attenuation by the local environment of the ground terminal (buildings, trees, etc.);
- g) short-term variations of the ratio of attenuations at the up- and down-link frequencies, which may affect the accuracy of adaptive fade countermeasures;
- h) for non-geostationary satellite (non-GSO) systems, the effect of varying elevation angle to the satellite.

Ionospheric effects (see Recommendation ITU-R P.531) may be important, particularly at frequencies below 1 GHz. For convenience these have been quantified for frequencies of 0.1; 0.25; 0.5; 1; 3 and 10 GHz in Table 1 for a high value of total electron content (TEC). The effects include:

- j) Faraday rotation: a linearly polarized wave propagating through the ionosphere undergoes a progressive rotation of the plane of polarization;
- k) dispersion, which results in a differential time delay across the bandwidth of the transmitted signal;
- l) excess time delay;
- m) ionospheric scintillation: inhomogeneities of electron density in the ionosphere cause refractive focusing or defocusing of radio waves and lead to amplitude fluctuations termed scintillations. Ionospheric scintillation is maximum near the geomagnetic equator and smallest in the mid-latitude regions. The auroral zones are also regions of large scintillation. Strong scintillation is Rayleigh distributed in amplitude; weaker scintillation is nearly log-normal. These fluctuations decrease with increasing frequency and depend upon path geometry, location, season, solar activity and local time. Table 2 tabulates fade depth data for VHF and UHF in mid-latitudes, based on data in Recommendation ITU-R P.531.

Accompanying the amplitude fluctuation is also a phase fluctuation. The spectral density of the phase fluctuation is proportional to $1/f^3$, where f is the Fourier frequency of the fluctuation. This spectral characteristic is similar to that arising from flicker of frequency in oscillators and can cause significant degradation to the performance of receiver hardware.

TABLE 1
Estimated* ionospheric effects for elevation angles of about 30° one-way traversal**
 (derived from Recommendation ITU-R P.531)

Effect	Frequency dependence	0.1 GHz	0.25 GHz	0.5 GHz	1 GHz	3 GHz	10 GHz
Faraday rotation	$1/f^2$	30 rotations	4.8 rotations	1.2 rotations	108°	12°	1.1°
Propagation delay	$1/f^2$	25 µs	4 µs	1 µs	0.25 µs	0.028 µs	0.0025 µs
Refraction	$1/f^2$	< 1°	< 0.16°	< 2.4'	< 0.6'	< 4.2"	< 0.36"
Variation in the direction of arrival (r.m.s.)	$1/f^2$	20'	3.2'	48"	12"	1.32"	0.12"
Absorption (auroral and/or polar cap)	$\approx 1/f^2$	5 dB	0.8 dB	0.2 dB	0.05 dB	6×10^{-3} dB	5×10^{-4} dB
Absorption (mid-latitude)	$1/f^2$	< 1 dB	< 0.16 dB	< 0.04 dB	< 0.01 dB	< 0.001 dB	< 1×10^{-4} dB
Dispersion	$1/f^3$	0.4 ps/Hz	0.026 ps/Hz	0.0032 ps/Hz	0.0004 ps/Hz	1.5×10^{-5} ps/Hz	4×10^{-7} ps/Hz
Scintillation ⁽¹⁾	See Rec. ITU-R P.531	See Rec. ITU-R P.531	See Rec. ITU-R P.531	See Rec. ITU-R P.531	> 20 dB peak-to-peak	≈ 10 dB peak-to-peak	≈ 4 dB peak-to-peak

* This estimate is based on a TEC of 10^{18} electrons/m², which is a high value of TEC encountered at low latitudes in daytime with high solar activity.

** Ionospheric effects above 10 GHz are negligible.

⁽¹⁾ Values observed near the geomagnetic equator during the early night-time hours (local time) at equinox under conditions of high sunspot number.

TABLE 2

Distribution of mid-latitude fade depths due to ionospheric scintillation (dB)

Percentage of time (%)	Frequency (GHz)			
	0.1	0.2	0.5	1
1	5.9	1.5	0.2	0.1
0.5	9.3	2.3	0.4	0.1
0.2	16.6	4.2	0.7	0.2
0.1	25	6.2	1	0.3

This Annex deals only with the effects of the troposphere on the wanted signal in relation to system planning. Interference aspects are treated in separate Recommendations:

- interference between earth stations and terrestrial stations (Recommendation ITU-R P.452);
- interference from and to space stations (Recommendation ITU-R P.619);
- bidirectional coordination of earth stations (Recommendation ITU-R P.1412).

An apparent exception is path depolarization which, although of concern only from the standpoint of interference (e.g. between orthogonally-polarized signal transmissions), is directly related to the propagation impairments of the co-polarized direct signal.

The information is arranged according to the link parameters to be considered in actual system planning, rather than according to the physical phenomena causing the different effects. As far as possible, simple prediction methods covering practical applications are provided, along with indications of their range of validity. These relatively simple methods yield satisfactory results in most practical applications, despite the large variability (from year to year and from location to location) of propagation conditions.

As far as possible, the prediction methods in this Annex have been tested against measured data from the data banks of Radiocommunication Study Group 3 (see Recommendation ITU-R P.311).

2 Propagation loss

The propagation loss on an Earth-space path, relative to the free-space loss, is the sum of different contributions as follows:

- attenuation by atmospheric gases;
- attenuation by rain, other precipitation and clouds;
- focusing and defocusing;
- decrease in antenna gain due to wave-front incoherence;
- scintillation and multipath effects;
- attenuation by sand and dust storms.

Each of these contributions has its own characteristics as a function of frequency, geographic location and elevation angle. As a rule, at elevation angles above 10°, only gaseous attenuation, rain and cloud attenuation and possibly scintillation will be significant, depending on propagation conditions. For non-GSO systems, the variation in elevation angle should be included in the calculations, as described in § 8.

(In certain climatic zones, snow and ice accumulations on the surfaces of antenna reflectors and feeds can produce prolonged periods with severe attenuation, which might dominate even the annual cumulative distribution of attenuation.)

2.1 Attenuation due to atmospheric gases

Attenuation by atmospheric gases which is entirely caused by absorption depends mainly on frequency, elevation angle, altitude above sea level and water vapour density (absolute humidity). At frequencies below 10 GHz, it may normally be neglected. Its importance increases with frequency above 10 GHz, especially for low elevation angles. Annex 1 of Recommendation ITU-R P.676 gives a complete method for calculating gaseous attenuation, while Annex 2 of the same Recommendation gives an approximate method for frequencies up to 350 GHz.

At a given frequency the oxygen contribution to atmospheric absorption is relatively constant. However, both water vapour density and its vertical profile are quite variable. Typically, the maximum gaseous attenuation occurs during the season of maximum rainfall (see Recommendation ITU-R P.836).

2.2 Attenuation by precipitation and clouds

2.2.1 Prediction of attenuation statistics for an average year

The general method to predict attenuation due to precipitation and clouds along a slant propagation path is presented in § 2.2.1.1. The method to predict the probability of non-zero rain attenuation along a slant path is described in § 2.2.1.2.

If reliable long-term statistical attenuation data are available that were measured at an elevation angle and a frequency (or frequencies) different from those for which a prediction is needed, it is often preferable to scale these data to the elevation angle and frequency in question rather than using the general method. The recommended frequency-scaling method is found in § 2.2.1.3.

Site diversity effects may be estimated with the method of § 2.2.4.

2.2.1.1 Calculation of long-term rain attenuation statistics from point rainfall rate

The following procedure provides estimates of the long-term statistics of the slant-path rain attenuation at a given location for frequencies up to 55 GHz. The following parameters are required:

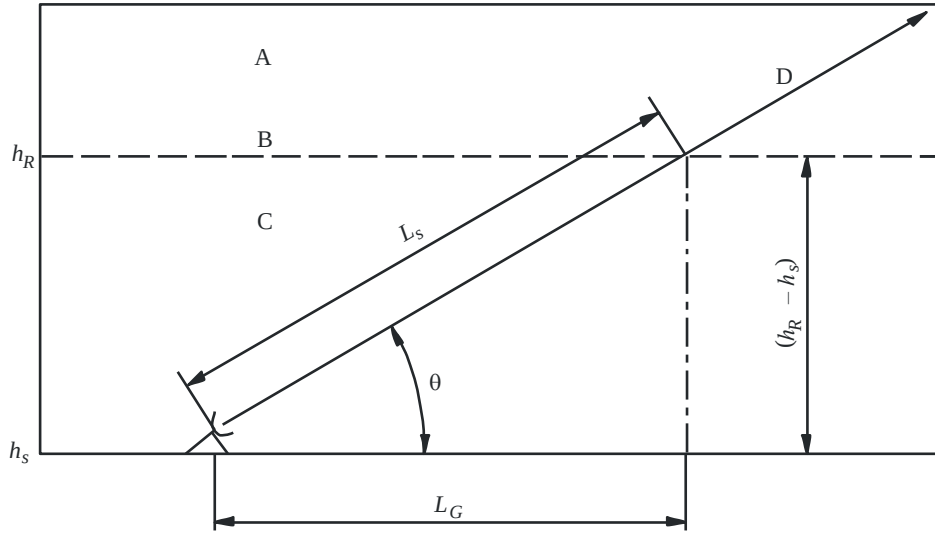
- $R_{0.01}$: point rainfall rate for the location for 0.01% of an average year (mm/h)
- h_s : height above mean sea level of the earth station (km)
- θ : elevation angle (degrees)
- φ : latitude of the earth station (degrees)
- f : frequency (GHz)
- R_e : effective radius of the Earth (8 500 km).

If local data for the earth station height above mean sea level is not available, an estimate can be obtained from the maps of topographic altitude given in Recommendation ITU-R P.1511.

The geometry is illustrated in Fig. 1.

FIGURE 1

Schematic presentation of an Earth-space path giving the parameters to be input into the attenuation prediction process



A: frozen precipitation
B: rain height
C: liquid precipitation
D: Earth-space path

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Step 1: Determine the rain height, h_R , as given in Recommendation ITU-R P.839.

Step 2: For $\theta \geq 5^\circ$ compute the slant-path length, L_s , below the rain height from:

$$L_s = \frac{(h_R - h_s)}{\sin \theta} \quad \text{km} \quad (1)$$

For $\theta < 5^\circ$, the following formula is used:

$$L_s = \frac{2(h_R - h_s)}{\left(\sin^2 \theta + \frac{2(h_R - h_s)}{R_e} \right)^{1/2} + \sin \theta} \quad \text{km} \quad (2)$$

If $h_R - h_s$ is less than or equal to zero, the predicted rain attenuation for any time percentage is zero and the following steps are not required.

Step 3: Calculate the horizontal projection, L_G , of the slant-path length from:

$$L_G = L_s \cos \theta \quad \text{km} \quad (3)$$

Step 4: Obtain the rainfall rate, $R_{0.01}$, exceeded for 0.01% of an average year (with an integration time of 1 min). If this long-term statistic cannot be obtained from local data sources, an estimate can be obtained from the maps of rainfall rate given in Recommendation ITU-R P.837. If $R_{0.01}$ is equal to zero, the predicted rain attenuation is zero for any time percentage and the following steps are not required.

Step 5: Obtain the specific attenuation, γ_R , using the frequency-dependent coefficients given in Recommendation ITU-R P.838 and the rainfall rate, $R_{0.01}$, determined from Step 4, by using:

$$\gamma_R = k (R_{0.01})^\alpha \quad \text{dB/km} \quad (4)$$

Step 6: Calculate the horizontal reduction factor, $r_{0.01}$, for 0.01% of the time:

$$r_{0.01} = \frac{1}{1 + 0.78 \sqrt{\frac{L_G \gamma_R}{f}} - 0.38 (1 - e^{-2L_G})} \quad (5)$$

Step 7: Calculate the vertical adjustment factor, $v_{0.01}$, for 0.01% of the time:

$$\zeta = \tan^{-1} \left(\frac{h_R - h_s}{L_G r_{0.01}} \right) \quad \text{degrees}$$

For $\zeta > \theta$,

$$L_R = \frac{L_G r_{0.01}}{\cos \theta} \quad \text{km}$$

Else,

$$L_R = \frac{(h_R - h_s)}{\sin \theta} \quad \text{km}$$

If $|\varphi| < 36^\circ$,

$$\chi = 36 - |\varphi| \quad \text{degrees}$$

Else,

$$\chi = 0 \quad \text{degrees}$$

$$v_{0.01} = \frac{1}{1 + \sqrt{\sin \theta} \left(31 \left(1 - e^{-(\theta/(1+\chi))} \right) \frac{\sqrt{L_R \gamma_R}}{f^2} - 0.45 \right)}$$

Step 8: The effective path length is:

$$L_E = L_R v_{0.01} \quad \text{km} \quad (6)$$

Step 9: The predicted attenuation exceeded for 0.01% of an average year is obtained from:

$$A_{0.01} = \gamma_R L_E \quad \text{dB} \quad (7)$$

Step 10: The estimated attenuation to be exceeded for other percentages of an average year, in the range 0.001% to 5%, is determined from the attenuation to be exceeded for 0.01% for an average year:

If $p \geq 1\%$ or $|\varphi| \geq 36^\circ$: $\beta = 0$

If $p < 1\%$ and $|\varphi| < 36^\circ$ and $\theta \geq 25^\circ$: $\beta = -0.005(|\varphi| - 36)$

Otherwise: $\beta = -0.005(|\varphi| - 36) + 1.8 - 4.25 \sin \theta$

$$A_p = A_{0.01} \left(\frac{p}{0.01} \right)^{-(0.655 + 0.033 \ln(p) - 0.045 \ln(A_{0.01}) - \beta(1-p) \sin \theta)} \quad \text{dB} \quad (8)$$

This method provides an estimate of the long-term statistics of attenuation due to rain. When comparing measured statistics with the prediction, allowance should be given for the rather large year-to-year variability in rainfall rate statistics (see Recommendation ITU-R P.678).