

RECOMMENDATION ITU-R P.1622

**Prediction methods required for the design of Earth-space systems
operating between 20 THz and 375 THz**

(Question ITU-R 228/3)

(2003)

The ITU Radiocommunication Assembly,

considering

- a) that the spectrum between 20 THz and 375 THz is suitable for certain space-based communications in near-Earth and deep space environments;
- b) that for the proper planning of Earth-space systems operating between 20 THz and 375 THz, it is necessary to have appropriate propagation prediction techniques;
- c) that methods have been developed for the prediction of the most significant propagation-related impacts to Earth-space systems operating between 20 THz and 375 THz;
- d) 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 planning of systems operating between 20 THz and 375 THz,

recognizing

- a) that No. 78 of Article 12 of the ITU Constitution states that a function of the Radio-communication Sector includes, "... carrying out studies without limit of frequency range and adopting recommendations ...",

recommends

- 1 that the methods for predicting propagation-related system impacts given in Annexes 1 and 2 be used for planning Earth-space systems in the respective ranges of validity indicated in Annexes 1 and 2.

NOTE 1 – Supplementary information related to fundamental propagation data for frequencies between 20 THz and 375 THz may be found in Recommendation ITU-R P.1621.

Annex 1**1 Introduction**

The Earth's atmosphere is complex and dynamic and will impact the performance of a system operating in the frequency range 20 THz to 375 THz between the Earth and an orbiting spacecraft. These system impacts include:

- an overall loss in signal amplitude due to absorption by molecules of atmospheric gasses present along the propagation path;

- an overall loss in signal amplitude and an increase in background noise due to scattering by particles ranging in size from fractions of a wavelength to many wavelengths present along the propagation path;
- fluctuations in the received amplitude and phase of the signal due to turbulence caused by thermal variations in the atmosphere.

The representative techniques and equations required to carry out the necessary prediction methods are presented in the following sections of this Annex.

2 Absorption losses

Calculations of atmospheric absorption are possible using a line-by-line method similar to that which is provided in Recommendation ITU-R P.676. However, as thousands of individual lines are present across the spectral range from 10 THz to 1 000 THz (30 μm to 0.3 μm), such a method is computationally intensive and cumbersome. The windows of low atmospheric absorption are identified within the astronomical community with standardized filters as described in Table 1. The centre frequencies of these filters provide an estimate of the regions of spectrum usable for communication along Earth-space paths in terms of the absorptive characteristics of the atmosphere only. As absorption is dependent, in part on local temperature, pressure, and atmospheric chemistry, the bandwidth of the filters does not necessarily correspond with the bandwidth of the regions of low atmospheric absorption. The four highest frequency bands represent a continuum of visible and ultraviolet spectrum with relatively low atmospheric absorption rather than distinct low absorption regions. Measurements of atmospheric absorption should be conducted whenever possible prior to the deployment of an earth station.

TABLE 1

Standard astronomical filters for frequencies above 15 THz

Filter		Q	N	M	L'	L	K	H
Centre frequency	(THz)	15	30	63	79	86	136	180
Wavelength	(μm)	20.25	10.1	4.80	3.80	3.50	2.20	1.65
Bandwidth	(THz)	15.2	18.2	15.9	14.7	17.3	30.1	33.3
	(μm)	6.50	5.70	1.20	0.70	0.70	0.48	0.30

Filter		J	I _J	I _S	R	V	B	U
Centre frequency	(THz)	240	330	370	430	560	700	830
Wavelength	(μm)	1.25	0.90	0.80	0.70	0.54	0.43	0.36
Bandwidth	(THz)	74.7	90.5	115.1	138.1	93.2	164.5	163.6
	(μm)	0.38	0.24	0.24	0.22	0.09	0.10	0.07

3 Scattering losses

Scattering is generally defined as the redirection of energy by particles present along the propagation path. The primary effects to communication systems operating at frequencies between 20 THz and 375 THz in free space appear when:

- particles with a diameter approximately equal to the transmitted signal wavelength, present along the propagation path, redirect the transmitted signal away from its intended path;
- particles with a diameter much smaller than the transmitted signal wavelength, present in the propagating medium, redirect extraneous energy into the intended receiver.

3.1 Attenuation of the transmitted signal due to Mie scattering

Mie scattering is the predominant source of losses at frequencies below 375 THz, and is largely caused by microscopic particles of water.

When local measurements characterizing the atmosphere are not available, the method described below can be used for calculating attenuation due to scattering along Earth-space paths. If measurements are available, a detailed calculation, provided in Annex 2, may be used.

The following method is appropriate for earth stations located at altitudes between 0 and 5 km above sea level and between 150 THz and 375 THz, the frequencies most often associated with telecommunication through free space. The method is accurate to within approximately 0.1 dB assuming elevation angles above 45°. However, local atmospheric conditions may lead to several dBs of variability.

The following parameters are required:

λ : wavelength (μm)

h_E : height of the earth station above mean sea level (km)

θ : elevation angle.

Step 1: Calculate the wavelength-dependent empirical coefficients:

$$a = -0.000545\lambda^2 + 0.002\lambda - 0.0038 \quad (1a)$$

$$b = 0.00628\lambda^2 - 0.0232\lambda + 0.0439 \quad (1b)$$

$$c = -0.028\lambda^2 + 0.101\lambda - 0.18 \quad (1c)$$

$$d = -0.228\lambda^3 + 0.922\lambda^2 - 1.26\lambda + 0.719 \quad (1d)$$

Step 2: Calculate the extinction ratio, τ' , from h_E to ∞ :

$$\tau' = a \cdot h_E^3 + b \cdot h_E^2 + c \cdot h_E + d \quad \text{km}^{-1} \quad (2)$$

Step 3: Calculate atmospheric attenuation due to scattering, A_S , along path:

$$A_S = \frac{4.3429\tau'}{\sin(\theta)} \quad \text{dB} \quad (3)$$

3.2 Increases in background noise due to Rayleigh scattered solar energy

Rayleigh scattering is negligible for systems operating below 375 THz. The most significant result of Rayleigh scattering to systems operating above 375 THz is the introduction of background noise into receivers. Background noise appears in both the Earth-to-space and space-to-Earth directions. The primary noise source for earth stations operating with spacecraft comes from Rayleigh scatter of sunlight during daytime operations. Spacecraft pointed at the Earth will also encounter noise from sunlight scattered from the Earth's surface.

4 Effects of turbulence on systems operating between 20 THz and 375 THz

As discussed in Recommendation ITU-R P.1621, the magnitude of turbulence is measured in terms of a C_n^2 profile.

The impacts of turbulence can be generally categorized as:

- amplitude scintillation caused by a redistribution of energy within the beam;
- apparent changes in the angle of arrival of the incoming signal;
- beam wander resulting in deflection of the beam centroid away from the axis of propagation;
- beam spreading caused by unequal refraction across the wavefront resulting in decreased power in the plane of the receiving antenna's aperture.

4.1 Amplitude scintillation

Turbulence at frequencies between 150 THz and 375 THz causes Gaussian distributed fluctuations in the log-irradiance, N , of an incoming wave, called scintillation, by spatially redistributing its power across the surface of the wavefront randomly in time.

The strength of scintillation is measured in terms of the variance of the beam amplitude. The following parameters are required to calculate the strength of scintillation:

h_0 : height of earth station above ground level (m)

λ : wavelength

θ : elevation angle

Z : effective height of the turbulence (typically 20 000 m).

Scintillation is traditionally given in terms of the variance, σ^2 , of $\ln(N)$ by:

$$\sigma_{\ln N}^2 = 2.253 k^{7/6} \sec^{11/6} \varphi \int_{h_0}^Z C_n^2(h) h^{5/6} dh \quad N p^2 \quad (4a)$$

where:

k : wavenumber ($= 2\pi/\lambda$)

λ : wavelength (m)

φ : zenith angle

h : height above ground level (m).