

ITU-R

Radiocommunication Sector of ITU

Recommendation ITU-R P.1621-2 (07/2015)

Propagation data required for the design of Earth-space systems operating between 20 THz and 375 THz

P Series
Radiowave propagation



Foreword

The role of the Radiocommunication Sector is to ensure the rational, equitable, efficient and economical use of the radio-frequency spectrum by all radiocommunication services, including satellite services, and carry out studies without limit of frequency range on the basis of which Recommendations are adopted.

The regulatory and policy functions of the Radiocommunication Sector are performed by World and Regional Radiocommunication Conferences and Radiocommunication Assemblies supported by Study Groups.

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Series of ITU-R Recommendations

(Also available online at <http://www.itu.int/publ/R-REC/en>)

Series	Title
BO	Satellite delivery
BR	Recording for production, archival and play-out; film for television
BS	Broadcasting service (sound)
BT	Broadcasting service (television)
F	Fixed service
M	Mobile, radiodetermination, amateur and related satellite services
P	Radiowave propagation
RA	Radio astronomy
RS	Remote sensing systems
S	Fixed-satellite service
SA	Space applications and meteorology
SF	Frequency sharing and coordination between fixed-satellite and fixed service systems
SM	Spectrum management
SNG	Satellite news gathering
TF	Time signals and frequency standards emissions
V	Vocabulary and related subjects

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.1621-2

Propagation data required for the design of Earth-space systems operating between 20 THz and 375 THz

(Question ITU-R 228/3)

(2003-2005-2015)

The ITU Radiocommunication Assembly,

considering

- a) that the spectrum between 20 THz and 375 THz is available for 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 data;
- c) that methods have been developed that allow the calculation of the most important propagation parameters needed in planning 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 the 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 Radiocommunication Sector includes, "... carrying out studies without limit of frequency range and adopting recommendations ...",

recommends

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

NOTE 1 – Supplementary information related to propagation prediction methods for frequencies between 20 THz and 375 THz may be found in Recommendation ITU-R P.1622.

Annex 1**1 Atmospheric considerations**

The performance of a system operating in the 20-375 THz frequency range between the Earth and an orbiting spacecraft is affected by the atmosphere of the Earth. These atmospheric effects include:

- absorption by molecules of atmospheric gasses present along the propagation path resulting in an overall loss in signal amplitude;
- scattering by particles ranging in size from fractions of a wavelength to many wavelengths present along the propagation path resulting in an apparent loss in signal amplitude;

- refraction of the beam due to changes in atmospheric density along the propagation path resulting in an apparent movement in the position of the transmitting source;
- turbulence due to thermal variations in the atmosphere resulting in fluctuations in the received amplitude and phase of the signal.

This Annex deals only with the effects of the troposphere on the wanted signal. As far as possible, the prediction methods in this Annex have been tested against measurements on terrestrial-free space links and astronomical systems. These methods yield results suitable for basic system planning. However, due to the spatial and temporal variability of the atmosphere, local site surveys of propagation characteristics are essential prior to the deployment of any ground-based system operating between 20 THz and 375 THz.

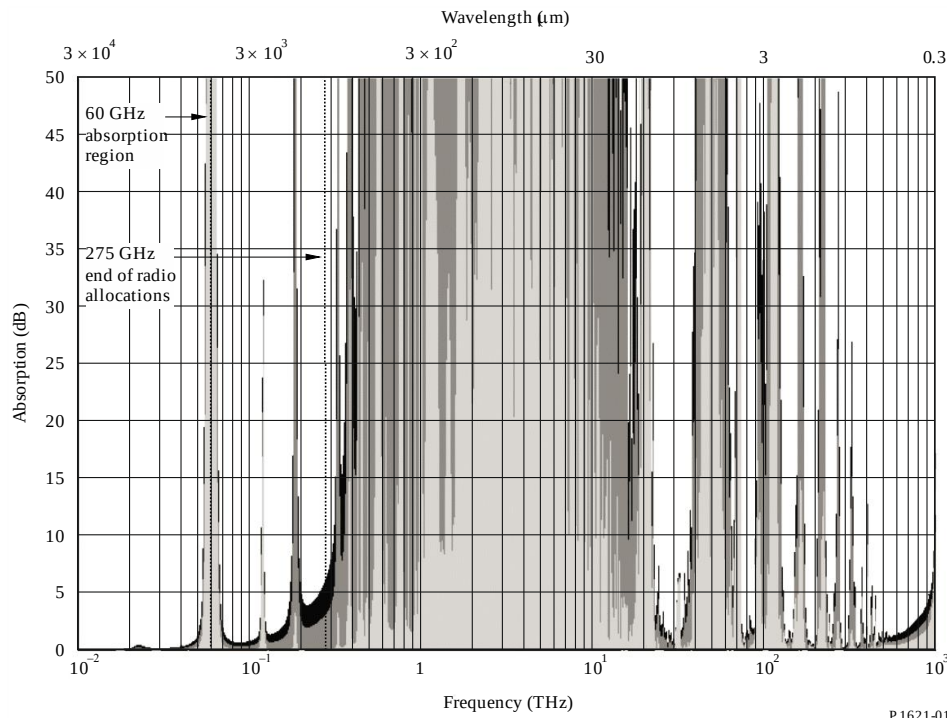
2 Absorption

Figure 1 illustrates the frequency dependence of atmospheric absorption along three zenith paths. The area shaded in light grey illustrates the relatively low absorption associated with a site located 5 km above sea level in an area of low humidity. The darker grey area shows the additional atmospheric absorption that would occur for a site located 2 km above sea level. The black regions show the further impact of atmospheric absorption for a site located at sea level and transmitting through a standard atmosphere as provided in Recommendation ITU-R P.835. The Figure clearly shows that the atmosphere, except at some dry, high altitude locations, is opaque to electromagnetic energy at almost all frequencies between about 1 THz and 10 THz (300 μm and 30 μm). Above 10 THz, the absorptive characteristics of the atmosphere again become favourable to propagating electromagnetic energy between the surface of the Earth and space.

The absorptive characteristics of the spectral region above 10 THz (below 30 μm), shown in detail in Fig. 2 for the same three zenith paths, are characterized by a series of regions of low absorption separated by strong but narrow regions of high absorption. The individual regions of low absorption are limited by a fine structure of many weak absorption lines. Individual absorption lines occur due to the presence of gaseous components in the atmosphere including, but not limited to: NH_3 , CO_2 , CO , CH_4 , NO_2 , NO , O_2 , O_3 , SO_2 , H_2O , and various CFCs. The strength of the absorption lines is dependent on temperature and pressure.

Calculations of atmospheric absorption are possible using a line-by-line method similar to Annex 1 of 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.

FIGURE 1
Atmospheric absorption along a vertical path



P.1621-01

3 Scattering

Atmospheric scatter results in an apparent reduction in signal strength at the receiver due to a redirection of the transmitted energy away from the intended propagation path. The scattering characteristics of the atmosphere are dependent on the diameter of the scattering particles present along the propagation path. Scattering characteristics take three forms:

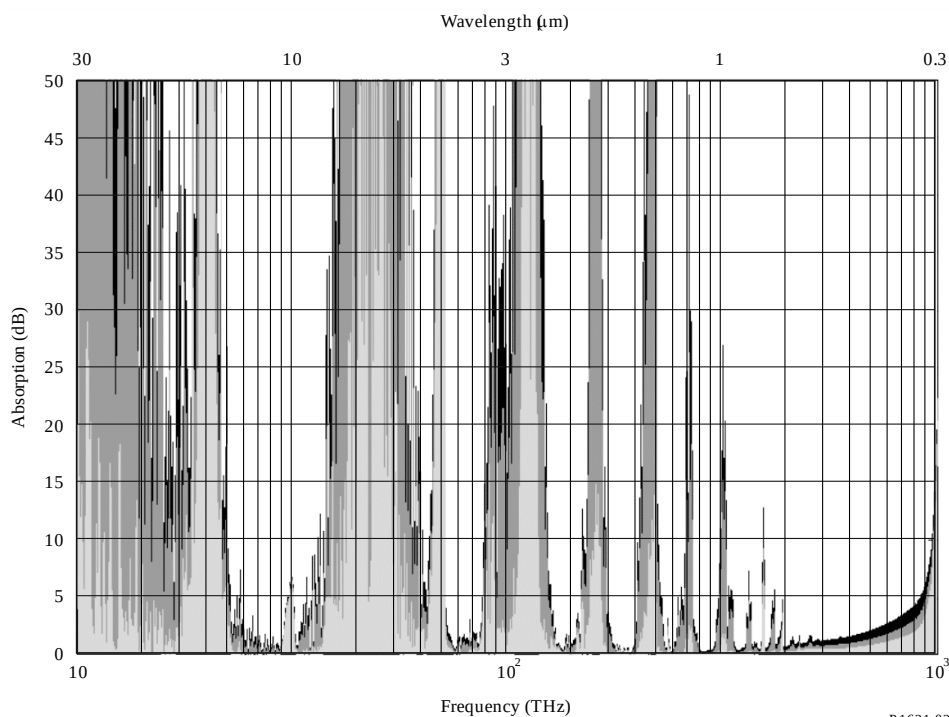
- Rayleigh
- Mie
- Wavelength independent.

3.1 Rayleigh scattering

The atmosphere exhibits Rayleigh scattering characteristics when the scattering particles along the propagation path have a much shorter physical diameter than the wavelength of the electromagnetic wave. At frequencies above 20 THz (wavelength below 15 μm), Rayleigh scattering occurs due to interactions between the electromagnetic wave and polar molecules of atmospheric gases.

FIGURE 2

Absorption above 10 THz (below 30 m) of a standard atmosphere along a vertical path



P.1621-02

The amount of apparent signal loss at the receiver attributable to Rayleigh scattering is negligible for frequencies below 375 THz (wavelength greater than 0.8 μm). However, the magnitude of Rayleigh scattering has a wavelength dependence of λ^{-4} . At about 1 000 THz (0.3 μm) the impact of Rayleigh scattering on a transmitted signal becomes comparable to Mie scattering.

The most significant result of Rayleigh scattering is the introduction of background noise into receivers. Background noise appears along paths 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 reflected from the Earth's surface, although this is not a Rayleigh effect.

Figure 3 provides the radiance, H , of the sky for several conditions each in $\text{W}/\text{m}^2/\mu\text{m}/\text{sr}$. For simplicity, Table 1 provides specific values of H for the primary frequencies of interest for space-based communication above 20 THz. A reasonable value of H during night-time operations is $\sim 1 \times 10^{-9} \text{ W}/\text{m}^2/\mu\text{m}/\text{sr}$ for most frequencies of interest.