



Recommendation ITU-R P.676-11
(09/2016)

Attenuation by atmospheric gases

P Series
Radiowave propagation



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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.676-11

Attenuation by atmospheric gases

(Question ITU-R 201/3)

(1990-1992-1995-1997-1999-2001-2005-2007-2009-2012-2013-2016)

Scope

This Recommendation provides methods to estimate the attenuation of atmospheric gases on terrestrial and slant paths using:

- a) an estimate of gaseous attenuation computed by a summation of individual absorption lines that is valid for the frequency range 1-1 000 GHz; and
- b) a simplified approximate method to estimate gaseous attenuation that is applicable in the frequency range 1-350 GHz.

Keywords: Gaseous absorption, specific attenuation, slant path attenuation, total attenuation, water vapour, oxygen, dry air

The ITU Radiocommunication Assembly,

considering

- a) the necessity of estimating the attenuation by atmospheric gases on terrestrial and slant paths,
- recommends*

1 that, for general application, the procedure in Annex 1 be used to calculate gaseous attenuation at frequencies up to 1 000 GHz;

2 that, for approximate estimates of gaseous attenuation in the frequency range 1-350 GHz, the computationally less intensive procedure given in Annex 2 is used.

Guide to this Recommendation

This Recommendation provides the following three methods of predicting the specific and path gaseous attenuation due to oxygen and water vapour:

- 1 Calculation of specific and path gaseous attenuation using the line-by-line summation in Annex 1 assuming the atmospheric pressure, temperature, and water vapour density vs. height;
- 2 An approximate estimate of specific and path gaseous attenuation in Annex 2 assuming the water vapour density at the surface of the Earth;
- 3 An approximate estimate of path attenuation in Annex 2 assuming the integrated water vapour content along the path.

These prediction methods can use local meteorological data, or, in the absence of local data, reference atmospheres or meteorological maps corresponding to a desired probability of exceedance that are provided in other ITU-R P-series Recommendations.

Specific attenuation

Annex 1 equation (1), which is applicable to frequencies up to 1 000 GHz, or the sum of Annex 2 equations (22) and (23), which is applicable to frequencies up to 350 GHz, may be used to predict specific attenuation. Both methods require the pressure, temperature, and water vapour density at the applicable location. If local data is not available, a combination of: a) the mean annual global

reference atmosphere given in Recommendation ITU-R P.835, b) the map of mean annual surface temperature in Recommendation ITU-R P.1510 and c) the maps of surface water vapour density vs. exceedance probability given in Recommendation ITU-R P.836 may be used in lieu of the standard ground-level surface water vapour density of 7.5 g/m³.

Slant path (Earth-space) attenuation

Annex 1 equation (20), or Annex 2 equations (28) or (29) may be used.

- Annex 1 equation (20) requires knowledge of the temperature, pressure, and water vapour density profiles along the path. If local profile data is not available, the reference atmospheric profiles given in Recommendation ITU-R P.835 may be used. The surface water vapour density vs. exceedance probability given in Recommendation ITU-R P.836 may be used in lieu of the standard ground-level surface water vapour density of 7.5 g/m³.
- Annex 2 equation (28) requires knowledge of the surface pressure, surface temperature, and surface water vapour density. Annex 2 equation (28) is an approximation to equation (20) applicable to frequencies up to 350 GHz assuming a mean annual global reference atmosphere and an arbitrary surface water vapour density with a negative exponential water vapour density profile vs. height. Annex 2 equation (28) can be used to predict: a) the instantaneous gaseous attenuation for a specific value of surface pressure, surface temperature, and surface water vapour density or b) the gaseous attenuation corresponding to the surface water vapour density at a desired probability of exceedance. If local surface water vapour density data is not available, the surface water vapour density maps in Recommendation ITU-R P.836 may be used.
- Annex 2 equation (29) requires knowledge of the surface temperature, surface pressure, and integrated water vapour content along the path. Similar to Annex 2 equation (28), Annex 2 equation (29) can be used to predict: a) the instantaneous gaseous attenuation for a specific value of surface pressure, surface temperature, and integrated water vapour content, or b) the gaseous attenuation corresponding to the integrated water vapour content at a desired probability of exceedance. If local surface integrated water vapour content data is not available, the integrated water vapour maps in Recommendation ITU-R P.836 may be used.

If local surface water vapour density and integrated water vapour content data are both available, Annex 2 equation (29) using local integrated water vapour content is considered to be more accurate than Annex 2 equation (28) using local surface water vapour density data. Similarly, if local data is not available, Annex 2 equation (29) using the maps of integrated water vapour content in Recommendation ITU-R P.836 is considered to be more accurate than Annex 2 equation (28) using the maps of surface water vapour density in Recommendation ITU-R P.836.

	Annex 1 Equation (20)	Annex 2 Equation (28)	Annex 2 Equation (29)
Frequency range	≤1 000 GHz	≤350 GHz	
Accuracy	Best, line-by-line sum	Approximation	
Pressure vs. height	Arbitrary	Mean Annual Global Reference Atmospheric Profile	
Temperature vs. height			
Water vapour density vs. height		Surface value with negative exponential profile vs. height	Integrated water vapour content in lieu of water vapour density vs. height

Annex 1

Line-by-line calculation of gaseous attenuation

1 Specific attenuation

The specific attenuation at frequencies up to 1 000 GHz, due to dry air and water vapour, can be evaluated most accurately at any value of pressure, temperature and humidity by means of a summation of the individual resonance lines from oxygen and water vapour, together with small additional factors for the non-resonant Debye spectrum of oxygen below 10 GHz, pressure-induced nitrogen attenuation above 100 GHz and a wet continuum to account for the excess water vapour-absorption found experimentally. Figure 1 shows the specific attenuation using the prediction method, calculated from 0 to 1 000 GHz at 1 GHz intervals, for a pressure of 1 013.25 hPa, temperature of 15° C for the cases of a water-vapour density of 7.5 g/m³ (Standard) and a dry atmosphere (Dry).

Near 60 GHz, many oxygen absorption lines merge together at sea-level pressures to form a single, broad absorption band, which is shown in more detail in Fig. 2. This figure also shows the oxygen attenuation at higher altitudes, with the individual lines becoming resolved as the pressure decreases with increasing altitude. Some additional molecular species (e.g. oxygen isotopic species, oxygen vibrationally excited species, ozone, ozone isotopic species, and ozone vibrationally excited species, and other minor species) are not included in the line-by-line prediction method. These additional lines are insignificant for typical atmospheres, but may be important for a dry atmosphere.

For quick and approximate estimates of specific attenuation at frequencies up to 350 GHz, in cases where high accuracy is not required, simplified algorithms are given in Annex 2 for restricted ranges of meteorological conditions.

The specific gaseous attenuation is given by:

$$\gamma = \gamma_o + \gamma_w = 0.1820 f \left(N''_{Oxygen}(f) + N''_{WaterVapour}(f) \right) \quad (\text{dB/km}) \quad (1)$$

here γ_o and γ_w are the specific attenuations (dB/km) due to dry air (oxygen, pressure-induced nitrogen and non-resonant Debye attenuation) and water vapour, respectively, f is the frequency (GHz), and $N''_{Oxygen}(f)$ and $N''_{Water Vapour}(f)$ are the imaginary parts of the frequency-dependent complex refractivities:

$$N''_{Oxygen}(f) = \sum_i (Oxygen) S_i F_i + N''_D(f) \quad (2a)$$

$$N''_{Water Vapour}(f) = \sum_i (Water Vapour) S_i F_i \quad (2b)$$

S_i is the strength of the i -th oxygen or water vapour line, F_i is the oxygen or water vapour line shape factor, and the summations extend over all the lines in Tables 1 and 2;

$N''_D(f)$ is the dry continuum due to pressure-induced nitrogen absorption and the Debye spectrum as given by equation (8).

The line strength is given by:

$$\begin{aligned} S_i &= a_1 \times 10^{-7} p \theta^3 \exp [a_2 (1 - \theta)] && \text{for oxygen} \\ &= b_1 \times 10^{-1} e \theta^{3.5} \exp [b_2 (1 - \theta)] && \text{for water vapour} \end{aligned} \quad (3)$$

where:

p : dry air pressure (hPa)

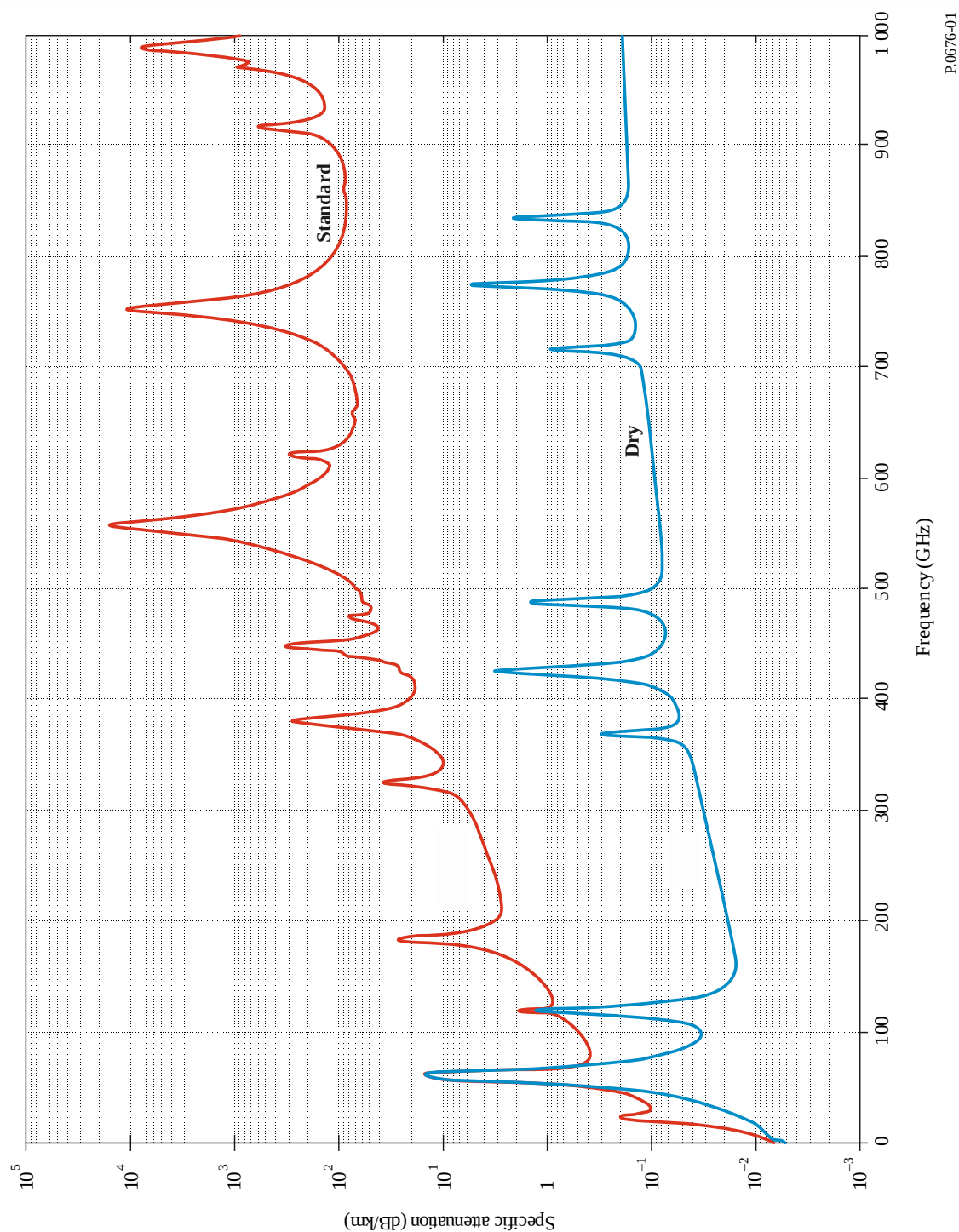
e : water vapour partial pressure (hPa) (total barometric pressure, $p_{tot} = p + e$)

$\theta = 300/T$

T : temperature (K).

FIGURE 1

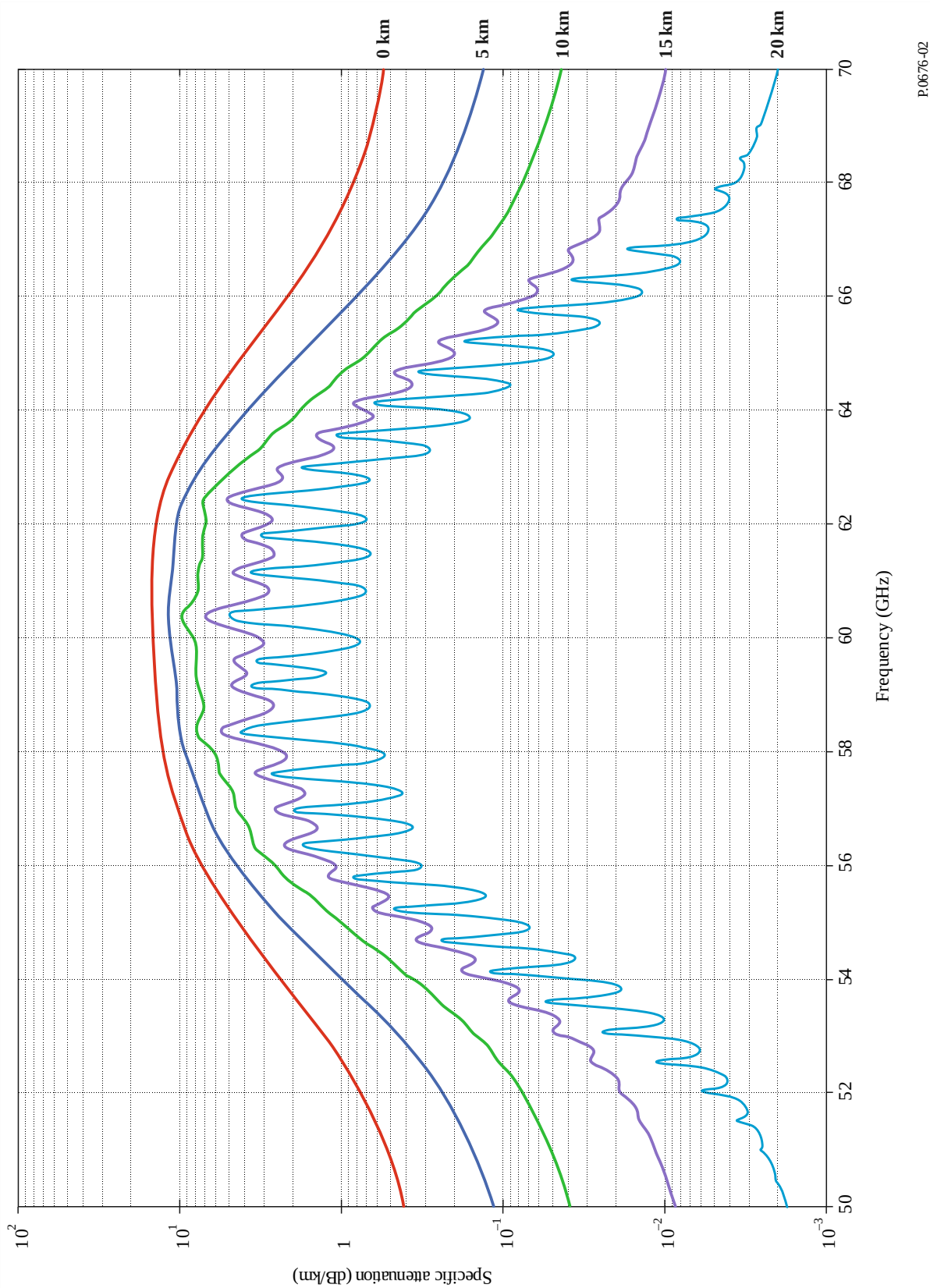
Specific attenuation due to atmospheric gases, calculated at 1 GHz intervals, including line centres



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FIGURE 2

Specific attenuation in the range 50-70 GHz at the altitudes indicated, calculated at intervals of 10 MHz, including line centres (0 km, 5 km, 10 km, 15 km and 20 km)



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If available, local altitude profiles of p , e and T (e.g. using radiosondes) should be used. In the absence of local information, a reference standard atmosphere given in Recommendation ITU-R P.835 should be used. (Note that where total atmospheric attenuation is being calculated, the same-water vapour partial pressure is used for both dry-air and water-vapour attenuations.)

The water-vapour partial pressure, e , at an altitude may be obtained from the water-vapour density, ρ , and the temperature, T , at that altitude using the expression:

$$e = \frac{\rho T}{216.7} \quad (4)$$

Spectroscopic data for oxygen is given in Table 1, and spectroscopic data for water vapour is given in Table 2. The last entry in Table 2 is a pseudo-line centred at 1 780 GHz whose lower wing represents the combined contribution below 1 000 GHz of water-vapour resonances not included in the line-by-line prediction method (i.e. the wet continuum). The pseudo-line's parameters are adjusted to account for the difference between the measured absorption in the atmospheric windows and the calculated local-line absorption.

The line-shape factor is given by:

$$F_i = \frac{f}{f_i} \left[\frac{\Delta f - \delta(f_i - f)}{(f_i - f)^2 + \Delta f^2} + \frac{\Delta f - \delta(f_i + f)}{(f_i + f)^2 + \Delta f^2} \right] \quad (5)$$

where f_i is the oxygen or water vapour line frequency and Δf is the width of the line:

$$\begin{aligned} \Delta f &= a_3 \times 10^{-4} (p \theta^{(0.8 - a_4)} + 1.1 e \theta) && \text{for oxygen} \\ &= b_3 \times 10^{-4} (p \theta^{b_4} + b_5 e \theta^{b_6}) && \text{for water vapour} \end{aligned} \quad (6a)$$

The line width Δf is modified to account for Zeeman splitting of oxygen lines and Doppler broadening of water vapour lines:

$$\begin{aligned} \Delta f &= \sqrt{\Delta f^2 + 2.25 \times 10^{-6}} && \text{for oxygen} \\ &= 0.535 \Delta f + \sqrt{0.217 \Delta f^2 + \frac{2.1316 \times 10^{-12} f_i^2}{\theta}} && \text{for water vapour} \end{aligned} \quad (6b)$$

δ is a correction factor that arises due to interference effects in oxygen lines:

$$\begin{aligned} \delta &= (a_5 + a_6 \theta) \times 10^{-4} (p + e) \theta^{0.8} && \text{for oxygen} \\ &= 0 && \text{for water vapour} \end{aligned} \quad (7)$$