



**Report ITU-R SA.2183**  
(10/2010)

**Method for calculating link performance  
in the space research service**

**SA Series**  
**Space applications and meteorology**



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***Note:** This ITU-R Report was approved in English by the Study Group under the procedure detailed in Resolution ITU-R 1.*

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## REPORT ITU-R SA.2183

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## 1 Introduction

This Report presents a method of calculating attenuation, noise temperature, and link performance, based on ITU-R Recommendations concerning the characteristics of radio wave propagation. The method can be extended to include equipment characteristics.

The method includes consideration of some effects that become important for systems with noise temperatures below about 30 K when operated in frequency bands below about 15 GHz. These factors are cosmic background noise, galactic noise, and the effect of atmospheric attenuation on their values. For many other systems with higher noise temperatures, these factors may be neglected.

The method will be explained in the context of providing data for the selection of preferred frequency bands on the basis of link performance.

## 2 References

The method and calculations to be described are based in part on the following Recommendations:

Recommendation ITU-R P.837-5 – Characteristics of precipitation for propagation modelling

Recommendation ITU-R P.618-9 – Propagation data and prediction methods required for the design of Earth-space telecommunications systems

Recommendation ITU-R P.676-7 – Attenuation by atmospheric gases

Recommendation ITU-R P.838-3 – Specific attenuation model for rain for use in prediction methods

Recommendation ITU-R P.372-9 – Radio noise

Recommendation ITU-R P.839-3 – Rain height model for prediction methods

Recommendation ITU-R P.525-2 – Calculation of free-space attenuation.

## 3 Types of analysis for frequency selection

For links between a spacecraft and the Earth, four types of analysis may be identified:

- space-to-Earth, as limited only by natural phenomena;
- space-to-Earth, including the effects of equipment;
- Earth-to-space, as limited only by natural phenomena;
- Earth-to-space, including the effects of equipment.

For the Earth-to-space link, contributions to the noise temperature of the spacecraft receiving system also include the cosmic and galactic backgrounds, but the contribution from the atmosphere of the Earth may be relatively small. For deep-space probes the Earth occupies such a small portion of the receiving antenna pattern that the noise temperature contribution of the atmosphere is negligible. The attenuation of the atmosphere must nevertheless be included in the link analysis since it directly affects the received signal power.

It is useful to consider links using two types of antennas. The first link assumes fixed diameter transmitting and receiving antennas. In this case the gain of both antennas varies with frequency. The second type of link assumes the use of one fixed diameter antenna and one fixed beamwidth antenna. In this case the gain of the fixed beam width antenna is nearly independent of frequency. An example of this case is the use of an omnidirectional antenna on a space station in order to allow communication during course correction maneuvers or loss of attitude control.

The shape of link performance curves depends on the antenna types assumed.

#### 4 Method for calculating link performance

The method for calculating link performance of space-to-Earth link under conditions of atmospheric attenuation and atmosphere plus rain attenuation is described. Tables 1 to 5 list the several parameters included in the calculation. The tables are:

1. Attenuation by atmospheric gasses and noise temperature as a function of frequency, elevation angle and water vapour density for atmospheric propagation.
2. Attenuation and noise temperature due to rainfall alone, as a function of frequency, elevation angle, and rain rate.
3. Attenuation and noise temperature for a propagation path including atmosphere plus rain, using data from Table 2.
4. Link performance for an assumed set of transmitter, antenna, and distance parameters, and considering the attenuation and noise temperature data from Table 1.
5. Link performance for an assumed set of transmitter, antenna, and distance parameters, considering the attenuation and noise temperature data from Table 3.

The tables are merely examples which show the various parameters and values for a few frequencies.

Values given in the tables are the result of analytic calculations. It should not be inferred that listing of these values to a precision of several decimal places is an indication of the accuracy or precision of the underlying propagation data or associated analytic expressions. Prediction of actual link performance to the indicated precision is not generally possible.

For a space-Earth propagation path through a rainy atmosphere, the attenuation is equal to the attenuation caused by the clear atmosphere along the path, plus the additional attenuation caused by the rainfall along the path. The attenuation caused by the atmosphere alone, and the attenuation caused by the rainfall alone are separately calculated (see Recommendation ITU-R P.618).

The sky noise temperature attributed to the rainy atmosphere is calculated with respect to the total attenuation, and is not equal to the sum of the noise temperatures that could be calculated for each of the two components of the total attenuation.

For each line in each table there is a description of the parameter or calculation and, usually, a particular information source is referenced.

#### 5 Calculations for atmospheric attenuation (no rain or clouds)

Table 1 presents calculated values of attenuation caused by the atmosphere, and of noise temperature caused by the combined effects of the cosmic background noise, galactic background noise, and the noise temperature related to attenuation by the atmosphere. The calculations shown in Table 1 are for conditions of atmospheric attenuation (no rain or clouds). Referring to the line numbers given at the left side of the table, the calculations are made as follows:

- Line 7      Water vapour density ( $\text{g/m}^3$ )  
                  Water vapour density in the atmosphere that is assumed for the particular calculation.
- Line 8      Station height above sea level (km)  
                  Height of the earth station above sea level. The example given in Table 1 is 0.81 km for the deep-space earth station at Madrid, Spain.
- Line 10     Frequency (GHz)  
                  Radio frequency for the particular calculation.

Line 12  $h_0$  (km)

Equivalent oxygen height at the earth station location. The equivalent oxygen height from sea level up to an altitude of about 10 km is given by:

$$h_0 = \frac{6.1}{1 + 0.17r_p^{-1.1}} (1 + t_1 + t_2 + t_3) \quad \text{km}$$

$$t_1 = \frac{4.64}{1 + 0.066r_p^{-2.3}} \exp \left[ - \left( \frac{f - 59.7}{2.87 + 12.4 \exp(-7.9r_p)} \right)^2 \right]$$

$$t_2 = \frac{0.14 \exp(2.12r_p)}{(f - 118.75)^2 + 0.031 \exp(2.2r_p)}$$

$$t_3 = \frac{0.0114}{1 + 0.14r_p^{-2.6}} f \frac{-0.0247 + 0.0001f + 1.61 \times 10^{-6} f^2}{1 - 0.0169f + 4.1 \times 10^{-5} f^2 + 3.2 \times 10^{-7} f^3}$$

$$h_0 \leq 10.7r_p^{0.3} \text{ when } f < 70 \text{ GHz}$$

where:

$f$ : frequency (GHz)

$r_p = p/1013$

$p$ : pressure (hPa) at the station location.

See § 2.2, Recommendation ITU-R P.676-7.

Line 13  $\gamma_0$  (dB/km)

Specific attenuation at ground level due to dry air, from sea level up to an altitude of 10 km, and for frequencies  $\leq 54$  GHz is given by:

$$\gamma_0 = \left[ \frac{7.2 r_t^{2.8}}{f^2 + 0.34 r_p^2 r_t^{1.6}} + \frac{0.62 \xi_3}{(54 - f)^{1.16 \xi_1} + 0.83 \xi_2} \right] f^2 r_p^2 \times 10^{-3} \quad \text{dB/km}$$

with:

$$\xi_1 = \varphi(r_p, r_t, 0.0717, -1.8132, 0.0156, -1.6515)$$

$$\xi_2 = \varphi(r_p, r_t, 0.5146, -4.6368, -0.1921, -5.7416)$$

$$\xi_3 = \varphi(r_p, r_t, 0.3414, -6.5851, 0.2130, -8.5854)$$

$$\varphi(r_p, r_t, a, b, c, d) = r_p^a r_t^b \exp[c(1 - r_p) + d(1 - r_t)]$$

where:

$$r_t = 288/(273 + t)$$

$t$ : temperature ( $^{\circ}\text{C}$ ), where mean temperature values can be obtained from map given in Recommendation ITU-R P.1510, when no adequate temperature data are available.

See § 2.1, Recommendation ITU-R P.676-7.

Line 14  $h_w$  (km)

Equivalent water vapour height at the earth station elevation. For frequencies < 350 GHz,  $h_w$  is given by:

$$h_w = 1.66 \left( 1 + \frac{1.39\sigma_w}{(f - 22.235)^2 + 2.56\sigma_w} + \frac{3.37\sigma_w}{(f - 183.31)^2 + 4.69\sigma_w} + \frac{1.58\sigma_w}{(f - 325.1)^2 + 2.89\sigma_w} \right)$$

for  $f \leq 350$  GHz

$$\sigma_w = \frac{1.013}{1 + \exp[-8.6(r_p - 0.57)]}$$

See § 2.2, Recommendation ITU-R P.676-7.

Line 15  $\gamma_w$  (dB/km)

Specific attenuation at ground level due to water vapour, from sea level up to an altitude of 10 km, and frequencies < 360 GHz is given by:

$$\gamma_w = \left\{ \begin{aligned} & \frac{3.98\eta_1 \exp[2.23(1-r_t)]}{(f - 22.235)^2 + 9.42\eta_1^2} g(f, 22) + \frac{11.96\eta_1 \exp[0.7(1-r_t)]}{(f - 183.31)^2 + 11.14\eta_1^2} \\ & + \frac{0.081\eta_1 \exp[6.44(1-r_t)]}{(f - 321.226)^2 + 6.29\eta_1^2} + \frac{3.66\eta_1 \exp[1.6(1-r_t)]}{(f - 325.153)^2 + 9.22\eta_1^2} \\ & + \frac{25.37\eta_1 \exp[1.09(1-r_t)]}{(f - 380)^2} + \frac{17.4\eta_1 \exp[1.46(1-r_t)]}{(f - 448)^2} \\ & + \frac{844.6\eta_1 \exp[0.17(1-r_t)]}{(f - 557)^2} g(f, 557) + \frac{290\eta_1 \exp[0.41(1-r_t)]}{(f - 752)^2} g(f, 752) \\ & + \frac{8.3328 \times 10^4 \eta_2 \exp[0.99(1-r_t)]}{(f - 1780)^2} g(f, 1780) \end{aligned} \right\} f^2 r_t^{2.5} \rho \times 10^{-4}$$

with:

$$\eta_1 = 0.955 r_p r_t^{0.68} + 0.006\rho$$

$$\eta_2 = 0.735 r_p r_t^{0.5} + 0.0353 r_t^4 \rho$$

$$g(f, f_i) = 1 + \left( \frac{f - f_i}{f + f_i} \right)^2$$

where:

$\rho$  : the water density (g/m<sup>3</sup>) at the station location

See § 2-1, Recommendation ITU-R P.676-7.

Line 17 Galactic temperature @ 408 MHz (K)

Galactic temperature for a particular region of the sky used to calculate the galactic noise temperature for other frequencies for the same region of the sky. For Table 1, a value of 30 K was arbitrarily selected.

See Recommendation ITU-R P.372-9.