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| **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

Method for calculating link performance in the space research service

(2010)

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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 (g/m3)

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:

 km



*h*0 ≤ 10.7*rp*0.3 when *f* < 70 GHz

where:

*f*: frequency (GHz)

*rp* = *p*/1 013

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

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

Line 13 γ0 (dB/km)

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

 dB/km

with:









where:

*rt* = 288/(273 + *t*)

*t*: temperature (°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 *hw* (km)

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





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

Line 15 γ*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:



with:



where:

ρ : the water density (g/m3) 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.

Line 18 Galactic temperature (K)

Temperature calculated for a particular frequency, given by:

(Galactic temperature @ 408 MHz) K

See § 6, Recommendation ITU‑R P.372-9.

Line 19 Cosmic noise power spectral density (W/Hz)

Power spectral density of the cosmic background noise given by:

         W/Hz

where:

*h*  6.626  10–34 (J/s) (Planck’s constant)

*f* :frequency (Hz)

*k*  1.3806  10–23 (J/K) (Boltzman’s constant)

*T* :noise temperature, taken as 2.7 K.

Line 20 Cosmic temperature (K)

Cosmic background noise temperature, given by:

Cosmic noise power spectral density / *k*          K

where *k* is Boltzman’s constant, 1.3806  10–23 (J/K).

Line 21 Cosmic  galactic temperature (K)

Sum of the cosmic and galactic noise temperatures at a particular frequency, and is given by:

Cosmic temperature  Galactic temperature          K

Line 23 Zenith attenuation (dB)

One-way attenuation through the atmosphere in the zenith direction, given by:

A = *h*0 γ0  *hw*γ*w* dB

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

Line 24 Zenith atmospheric noise temperature (K)

Noise temperature caused by the atmosphere in the zenith direction (*tb*) is given by:

*tb* = 280 (1 − 10−*A*/10) K

where 280 is the mean radiating temperature of the atmosphere and A (dB) is the one‑way attenuation through the atmosphere in the zenith direction.

See § 4, Recommendation ITU‑R P.372-9.

Line 25 Zenith background noise temperature (K)

Sum of the cosmic and galactic noise temperature, as reduced by the zenith attenuation, and is given by:

(Cosmic  Galactic temperature) /10*A*/10 K

See § 8, Recommendation ITU‑R P.372-9.

Line 26 Zenith noise temperature (K)

Sum of the zenith atmospheric noise temperature, and the zenith background noise temperature, given by:

Zenith atmospheric noise temperature  Zenith background noise temperature K

Line 29 Elevation angle (degrees)

Elevation angle of the earth station antenna for the particular calculation.

Line 30 Atmospheric attenuation (dB)

One-way attenuation through the atmosphere at the particular elevation angle, and for elevation angles greater than 10° given by:

*B = A* / sin(elevation angle) dB

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

Line 31 Atmospheric noise temperature (K)

Noise temperature caused by the atmosphere in the direction of the elevation angle, and given by:

280 (1 – 10–*B*/10) K

where 280 is the mean radiating temperature (K) of the atmosphere and *B* (dB) is the one-way attenuation through the atmosphere in the direction of the elevation angle.

Line 32 Background noise temperature (K)

Sum of the cosmic and galactic noise temperatures, as reduced by the attenuation at the particular elevation angle, given by:

(Cosmic  Galactic temperature) / 10*B*/10 K

where *B* (dB) is the one-way attenuation through the atmosphere in the direction of the elevation angle.

Line 33 Noise temperature (K)

Sum of the atmospheric noise and the background noise temperatures at the particular elevation angle, given by:

Atmospheric noise temperature  Background noise temperature K

Line 34 Noise power spectral density (dB(W/Hz))

Noise power spectral density corresponding to the noise temperature, and is given by:

–228.6  10 log(noise temperature) dB(W/Hz)

where –228.6 is the logarithmic expression of Boltzman’s constant, 1.3806  10−23 (J/K).

Lines 37-42 and 45-50 are similar to lines 29-34 except for the effects of different elevation angles.

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
|  | 1 | TABLE 1 | | | | |
|  | 2 | Data for selection of preferred frequencies  Attenuation and noise temperature, atmosphere, no rain | | | | |
|  | 3 |  | | | | |
|  | 4 |  | | | | |
|  | 5 |  | | | | |
|  | 6 | ------------------------------------------------------------------------------------------------------------------------------------------------- | | | | |
|  | 7 | Water vapour density (g/m3) | 0007.5 |  |  |  |
|  | 8 | Station height above sea level (km) | 0000.81 |  |  |  |
|  | 9 |  |  |  |  |  |
|  | 10 | Frequency (GHz) | 0001 | 0010 | 0020 | 0030 |
|  | 11 |  |  |  |  |  |
|  | 12 | *h*0 (km) | 0005.213 | 0005.200 | 0005.181 | 0005.156 |
|  | 13 | γ0 (dB/km) | 0000.005 | 0000.008 | 0000.011 | 0000.021 |
|  | 14 | *hw*(km) | 0001.665 | 0001.675 | 0001.963 | 0001.697 |
|  | 15 | γ*w*(dB/km) | 0005.668E-5 | 0000.007 | 0000.101 | 0000.080 |
|  | 16 |  |  |  |  |  |
|  | 17 | Galactic temperature @ 408 MHz (K) | 00 30 |  |  |  |
|  | 18 | Galactic temperature (K) | 0002.549 | 0000.005 | 0000.001 | 0000.000 |
|  | 19 | Cosmic noise power spectral density (W/Hz) | 0003.69E-23 | 0003.41E-23 | 0003.10E-23 | 0002.82E-23 |
|  | 20 | Cosmic temperature (K) | 0002.676 | 0002.467 | 0002.248 | 0002.044 |
|  | 21 | Cosmic  galactic temperature (K) | 0005.225 | 0002.472 | 0002.249 | 0002.044 |
|  | 22 |  |  |  |  |  |
|  | 23 | Zenith attenuation (dB) | 0000.028 | 0000.052 | 0000.256 | 0000.241 |
|  | 24 | Zenith atmospheric noise temperature (K) | 0001.808 | 0003.348 | 00 16.030 | 0015.120 |
|  | 25 | Zenith background noise temperature (K) | 0005.192 | 0002.442 | 0002.120 | 0001.934 |
|  | 26 | Zenith noise temperature (K) | 0007.000 | 0005.790 | 00 18.150 | 0017.054 |
|  | 27 |  |  |  |  |  |
|  | 28 |  |  |  |  |  |
|  | 29 | Elevation angle (degrees) | 00 15.00 |  |  |  |
|  | 30 | Atmospheric attenuation (dB) | 0000.109 | 00 0.202 | 0000.989 | 0000.932 |
|  | 31 | Atmospheric noise temperature (K) | 0006.921 | 00 12.714 | 00 57.036 | 0054.052 |
|  | 32 | Background noise temperature (K) | 0005.096 | 0002.359 | 0001.791 | 0001.649 |
|  | 33 | Noise temperature (K) | 00 12.018 | 00 15.073 | 00 58.826 | 0055.702 |
|  | 34 | Noise power spectral density (dB(W/Hz)) | –217.801 | –216.818 | –210.90 | –211.14 |
|  | 35 |  |  |  |  |  |
|  | 36 |  |  |  |  |  |
|  | 37 | Elevation angle (degrees) | 00 30.00 |  |  |  |
|  | 38 | Atmospheric attenuation (dB) | 0000.056 | 0000.104 | 0000.512 | 0000.482 |
|  | 39 | Atmospheric noise temperature (K) | 0003.604 | 0006.655 | 00 31.142 | 0029.424 |
|  | 40 | Background noise temperature (K) | 0005.158 | 0002.413 | 0001.999 | 0001.829 |
|  | 41 | Noise temperature (K) | 0008.763 | 0009.068 | 00 33.141 | 00 31.253 |
|  | 42 | Noise power spectral density (dB(W/Hz)) | –219.17 | –219.025 | –213.40 | –213.65 |
|  | 43 |  |  |  |  |  |
|  | 44 |  |  |  |  |  |
|  | 45 | Elevation angle (degrees) | 00 75.00 |  |  |  |
|  | 46 | Atmospheric attenuation (dB) | 0000.029 | 0000.054 | 0000.265 | 0000.250 |
|  | 47 | Atmospheric noise temperature (K) | 0001.872 | 0003.465 | 00 16.578 | 0015.638 |
|  | 48 | Background noise temperature (K) | 0005.191 | 0002.441 | 0002.116 | 0001.930 |
|  | 49 | Noise temperature (K) | 0007.062 | 0005.906 | 00 18.694 | 0017.568 |
|  | 50 | Noise power spectral density (dB(W/Hz)) | –220.11 | –220.89 | – 215.88 | –216.15 |

# 6 Calculations for rain attenuation

Table 2 presents data showing attenuation and noise temperature resulting from the effects of rain (hydrometeors) alone, not including effects of the gaseous atmosphere. Referring to the line numbers given at the left side of the table, the calculations are made as follows:

Line 6 Station latitude (degrees)

Latitude of the earth station. The example given in Table 2 is 40° for the deep-space earth station at Madrid, Spain.

Line 7 Station height above sea level (km), h*s*

*hs*= Height of the earth station above sea level: 0.81 km for Madrid, Spain.

Line 8 Rain rate (mm/h)

Rain rate exceeded 0.01% of the year, and for this example is 32 mm/h for Madrid, Spain. See § 2.2.1.1, Step 4, Recommendation ITU‑R P.618-9 and Fig. 1 and Table 1, Recommendation ITU‑R P.837-5.

Line 9 Rain height (km) above mean sea level, h*r*, is given by:

*hr*= (0°C-isotherm height) + 0.36  km

For easy reference the value of hr can be obtained from Fig. 1 of Recommendation ITU‑R P.839-3. See § 2.2.1.1, Step 1, Recommendation ITU‑R P.618-9 and Recommendation ITU‑R P.839-3.

Line 11 Frequency (GHz)

Line 13 Coefficient *kH*

Coefficient used for estimating specific attenuation due to rain.

For values of *kH* not given directly in Table 5 of Recommendation ITU‑R P.838-3, the formula for interpolation is:



where *f* is frequency (GHz). Coefficients for constants a*j*, b*j*, c*j*, m*k*, and c*k* are available in Tables 1-4 of Recommendation ITU‑R P.838-3.

See Recommendation ITU‑R P.838-3.

Line 14 Coefficient α*H*

Coefficient used for estimating specific attenuation due to rain.

For values of α*H*not given directly in Table 5 of Recommendation ITU‑R P.838-3, the formula for interpolation is:



Coefficients for constants a*j*, b*j*, c*j*, mα, and cα are available in Tables 1-4 of Recommendation ITU‑R P.838-3.

See Recommendation ITU‑R P.838-3.

Line 15 Coefficient *kV*

Coefficient used for estimating specific attenuation due to rain.

For values of *kV* not given directly in Table 5 of Recommendation ITU‑R P.838-3, the formula for interpolation is:



where *f* is frequency (GHz). Coefficients for constants a*j*, b*j*, c*j*, m*k*, and c*k* are available in Tables 1-4 of Recommendation ITU‑R P.838-3.

Line 16 Coefficient α*V*

Coefficient used for estimating specific attenuation due to rain.

For values of α*V* not given directly in Table 5 of Recommendation ITU‑R P.838-3, the formula for interpolation is:



Coefficients for constants a*j*, b*j*, c*j*, mα, and cα are available in Tables 1-4 of Recommendation ITU‑R P.838-3.

See Recommendation ITU-R P.838-3.

Line 18 Elevation angle (θ)

Line 19 Slant path (km), L*s*

Length of the slant path below the rain height is given by:

For θ ≥ 5°

  km

For θ < 5°

  km

See § 2.2.1.1, Step 2, Recommendation ITU‑R P.618-9.

Line 20 Horizontal projection (km), L*g*

Horizontal projection of the slant path, given by:

*Lg*  = *Ls*  cos(θ) km

See § 2.2.1.1, Step 3, Recommendation ITU‑R P.618-9.

Line 21 Coefficient k

Coefficient used for estimating specific attenuation due to rain:

k = [kH + kV + (kH − kV) cos2(θ) cos(2τ)] / 2

where τ is the polarization tilt angle relative to the horizontal (τ = 45° for circular polarization).

See Recommendation ITU‑R P.838-3.

Line 22 Coefficient α

Coefficient used for estimating specific attenuation due to rain:

α = [kHαH + kVαV + (kHαH − kVαV) cos2(θ) cos(2τ)] / 2k

See Recommendation ITU‑R P.838-3.

Line 23 γ*R* (dB/km)

Specific attenuation due to rain given by:

γ*R*= k (Rain Rate)α    dB/km

Line 24 Horizontal reduction, *r*0.01 for 0.01%

Horizontal Reduction factor for 0.01% of the time, given by:



See § 2.2.1.1, Step 6, Recommendation ITU‑R P.618-9.

Line 25 Vertical reduction, 0.01, for 0.01%

Vertical reduction factor for 0.01% of the time:



For   , 

Else, 

If |  |  36,   36 – |  |           degrees

Else,   0           degrees



Line 26 Effective path length, L*e*

The effective path length is given by:

*Le*= *LR* 0.01    km

Line 27 Attenuation 0.01% (dB)

Rain attenuation exceeded 0.01% of the year, given by:

A0.01= γ*R* *Le*

See § 2.2.1.1, Step 7, Recommendation ITU‑R P.618-9.

Line 28 Attenuation p% (dB), A*p*

Rain attenuation exceeded p% of the year, and is given by:

If *p*  1 or |  |  36:

  0

If *p* < 1 and |  | < 36 and   25:

  –0.005(|  | – 36)

Otherwise:

  –0.005(|  | – 36) + 1.8 – 4.25 sin 



NOTE 1 – The selection of a particular percentage of time is based on operational considerations. 0.1% is appropriate for some space research missions and was chosen for this example in order to illustrate the method of calculation.

See § 2.2.1.1, Step10, Recommendation ITU‑R P.618-9.

Lines 31-41 and 44-54 are similar to lines 18-28 except for the effects of different elevation angles.

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| 1 | | TABLE 2 | | | | |
| 2 | | Data for selection of preferred frequencies  Attenuation caused by rainfall alone, without atmosphere | | | | |
| 3 | |  | | | | |
| 4 | |  | | | | |
| 5 | | ---------------------------------------------------------------------------------------------------------------------------------- | | | | |
| 6 | | Station latitude (degrees) | 40 |  |  |  |
| 7 | | Station height above sea level (km) | 0.81 |  |  |  |
| 8 | | Rain rate (mm/h) 0.01% | 32 |  |  |  |
| 9 | | Rain height (km) | 3.7 |  |  |  |
| 10 | |  |  |  |  |  |
| 11 | | Frequency (GHz) | 1 | 10 | 20 | 30 |
| 12 | |  |  |  |  |  |
| 13 | | Coefficient *kH* | 0.000026 | 0.0122 | 0.092 | 0.240 |
| 14 | | Coefficient α*H* | 0.969 | 1.257 | 1.057 | 0.949 |
| 15 | | Coefficient kV | 0.000031 | 0.0113 | 0.096 | 0.229 |
| 16 | | Coefficient αV | 0.859 | 1.216 | 0.985 | 0.913 |
| 17 | |  |  |  |  |  |
| 18 | | Elevation angle (degrees) | 15 | 15 | 15 | 15 |
| 19 | | Slant path (km) | 11.17 | 11.17 | 11.17 | 11.17 |
| 20 | | Horizontal projection (km) | 10.79 | 10.79 | 10.79 | 10.79 |
| 21 | | Coefficient k | 2.835E-5 | 0.012 | 0.094 | 0.235 |
| 22 | | Coefficient α | 0.909 | 1.237 | 1.020 | 0.931 |
| 23 | | γ*R*(dB/km) | 6.63E-4 | 0.854 | 3.218 | 5.915 |
| 24 | | Horizontal reduction 0.01% | 1.458 | 0.731 | 0.607 | 0.569 |
| 25 | | Vertical reduction 0.01% | 0.470 | 0.842 | 1.047 | 1.138 |
| 26 | | Effective path length (km) | 5.248 | 6.872 | 7.095 | 7.232 |
| 27 | | Attenuation 0.01% (dB) | 0.003 | 5.867 | 22.834 | 42.781 |
| 28 | | Attenuation p = 0.1 (dB) | 5.10E-4 | 1.858 | 8.324 | 16.644 |
| 29 | |  |  |  |  |  |
| 30 | |  |  |  |  |  |
| 31 | | Elevation angle (degrees) | 30 | 30 | 30 | 30 |
| 32 | | Slant path (km) | 5.78 | 5.78 | 5.78 | 5.78 |
| 33 | | Horizontal projection (km) | 5.006 | 5.006 | 5.006 | 5.006 |
| 34 | | Coefficient k | 2.835E-5 | 0.012 | 0.094 | 0.235 |
| 35 | | Coefficient α | 0.909 | 1.237 | 1.020 | 0.931 |
| 36 | γ*R*(dB/km) | | 6.63E-4 | 0.854 | 3.218 | 5.915 |
| 37 | Horizontal reduction 0.01% | | 1.504 | 0.885 | 0.758 | 0.717 |
| 38 | | Vertical reduction 0.01% | 0.491 | 0.877 | 1.127 | 1.246 |
| 39 | | Effective path length (km) | 2.836 | 4.487 | 4.934 | 5.164 |
| 40 | | Attenuation 0.01% (dB) | 0.002 | 3.831 | 15.878 | 30.54 |
| 41 | | Attenuation p = 0.1 (dB) | 2.585E-4 | 1.161 | 5.574 | 11.48 |
| 42 | |  |  |  |  |  |
| 43 | |  |  |  |  |  |
| 44 | | Elevation angle (degrees) | 75 | 75 | 75 | 75 |
| 45 | | Slant path (km) | 2.992 | 2.992 | 2.992 | 2.992 |
| 46 | | Horizontal projection (km) | 0.774 | 0.774 | 0.774 | 0.774 |
| 47 | | Coefficient k | 2.835E-5 | 0.012 | 0.094 | 0.235 |
| 48 | | Coefficient α | 0.909 | 1.237 | 1.020 | 0.931 |
| 49 | | γ*R* (dB/km) | 6.627E-4 | 0.854 | 3.218 | 5.915 |
| 50 | | Horizontal reduction 0.01% | 1.392 | 1.109 | 1.024 | 0.994 |
| 51 | | Vertical reduction 0.01% | 0.522 | 0.957 | 1.259 | 1.429 |
| 52 | | Effective path length (km) | 1.563 | 2.864 | 3.768 | 4.252 |
| 53 | | Attenuation 0.01% (dB) | 0.001 | 2.445 | 12.126 | 25.153 |
| 54 | | Attenuation p = 0.1 (dB) | 1.340E-4 | 0.707 | 4.140 | 9.262 |

# 7 Calculations for atmosphere plus rain attenuation

Table 3 presents calculated values of attenuation caused by the clear atmosphere plus rain, and of noise temperature caused by the effects of the cosmic background noise, galactic background noise, and the noise temperature related to attenuation by the combination of atmosphere and rain. Referring to the line numbers given at the left side of the table, the calculations are made as follows:

Lines 1 through 26 are as explained for Table 1.

Line 27 Rain attenuation (dB)

Attenuation due to rain along a path at the specified elevation angle. The value given is the attenuation that is exceeded 0.1% of the time at Madrid and is obtained from Table 2.

Line 28 Total attenuation (dB)

B = Sum of the attenuation due to the atmosphere and the attenuation due to rain.

Line 29 Atmospheric  rain noise temperature (K)

Noise temperature due to the total attenuation, given by:

280 (1 – 10–*B*/10)          K

where 280 is the mean radiating temperature (K) of the atmosphere and *B* (dB) is the one-way total attenuation along the path.

Line 30 Background noise temperature (K)

Sum of the cosmic and galactic noise temperatures, as reduced by the attenuation at the particular elevation angle, given by:

(Cosmic  Galactic temperature) / 10*B*/10          K

where *B* (dB) is the one-way attenuation through the atmosphere in the direction of the elevation angle.

Line 31 Noise temperature (K)

Sum of the atmospheric and rain noise and the background noise for the particular elevation angle.

Line 32 Noise power spectral density (dB(W/Hz))

Noise power spectral density corresponding to the noise temperature, given by:

–228.6 + 10 log(noise temperature (K))          dB(W/Hz)

where –228.6 is the logarithmic expression of Boltzman’s constant,

Lines 34-50 are similar to lines 25-32 except for the effects of different elevation angles.

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
|  | 1 | TABLE 3 | | | | |
|  | 2 | Data for selection of preferred frequencies  Attenuation and noise temperature, atmosphere plus rain | | | | |
|  | 3 |  | | | | |
|  | 4 | ------------------------------------------------------------------------------------------------------------------------------------ | | | | |
|  | 5 | Water vapour density (g/m3) | 7.50 |  |  |  |
|  | 6 | Station height above sea level (km) | 0.81 |  |  |  |
|  | 7 | Frequency (GHz) | 1 | 10 | 20 | 30 |
|  | 8 |  |  |  |  |  |
|  | 9 | *h*0 (km) | 5.213 | 5.200 | 5.181 | 5.156 |
|  | 10 | γ0 (dB/km) | 0.005 | 0.008 | 0.011 | 0.020 |
|  | 11 | *hw* (km) | 1.665 | 1.675 | 1.963 | 1.696 |
|  | 12 | γ*w* (dB/km) | 5.668E-5 | 0.007 | 0.101 | 0.080 |
|  | 13 |  |  |  |  |  |
|  | 14 | Galactic temperature @ 408 MHz (K) | 30 |  |  |  |
|  | 15 | Galactic temperature (K) | 2.549 | 0.005 | 0.001 | 0.000 |
|  | 16 | Cosmic noise power spectral density (W/Hz) | 3.69E-23 | 3.41E-23 | 3.10E-23 | 2.82E-23 |
|  | 17 | Cosmic temperature (K) | 2.676 | 2.467 | 2.248 | 2.044 |
|  | 18 | Cosmic + galactic temperature (K) | 5.225 | 2.472 | 2.249 | 2.044 |
|  | 19 |  |  |  |  |  |
|  | 20 | Zenith attenuation (dB) | 0.028 | 0.052 | 0.256 | 0.241 |
|  | 21 | Zenith atmospheric noise temperature (K) | 1.808 | 3.348 | 16.030 | 15.120 |
|  | 22 | Zenith background noise temperature (K) | 5.192 | 2.442 | 2.120 | 1.934 |
|  | 23 | Zenith noise temperature (K) | 7.000 | 5.790 | 18.150 | 17.054 |
|  | 24 |  |  |  |  |  |
|  | 25 | Elevation angle (degrees) | 15.00 |  |  |  |
|  | 26 | Atmospheric attenuation (dB) | 0.109 | 0.202 | 0.989 | 0.932 |
|  | 27 | Rain attenuation (dB) | 5.10E-4 | 1.858 | 8.324 | 16.644 |
|  | 28 | Total attenuation dB | 0.109 | 2.060 | 9.313 | 17.575 |
|  | 29 | Atmospheric + rain noise temperature (K) | 6.953 | 105.75 | 247.20 | 275.107 |
|  | 30 | Background noise temperature (K) | 5.095 | 1.538 | 0.263 | 0.036 |
|  | 31 | Noise temperature (K) | 12.049 | 107.29 | 247.47 | 275.14 |
|  | 32 | Noise power spectral density (dB(W/Hz)) | –217.79 | –208.29 | –204.66 | –204.20 |
|  | 33 |  |  |  |  |  |
|  | 34 | Elevation angle (degrees) | 30.00 |  |  |  |
|  | 35 | Atmospheric attenuation (dB) | 0.056 | 0.104 | 0.512 | 0.482 |
|  | 36 | Rain attenuation (dB) | 2.585E-4 | 1.161 | 5.574 | 11.477 |
|  | 37 | Total attenuation (dB) | 0.056 | 1.265 | 6.086 | 11.959 |
|  | 38 | Atmospheric + rain noise temperature (K) | 3.621 | 70.772 | 211.05 | 262.166 |
|  | 39 | Background noise temperature (K) | 5.158 | 1.847 | 0.553 | 0.123 |
|  | 40 | Noise temperature (K) | 8.779 | 72.618 | 211.61 | 262.30 |
|  | 41 | Noise power spectral density (dB(W/Hz)) | –219.17 | –209.99 | –205.34 | –204.41 |
|  | 42 |  |  |  |  |  |
|  | 43 | Elevation angle (degrees) | 75.00 |  |  |  |
|  | 44 | Atmospheric attenuation (dB) | 0.029 | 0.054 | 0.265 | 0.250 |
|  | 45 | Rain attenuation (dB) | 1.340E-4 | 0.707 | 4.140 | 9.262 |
|  | 46 | Total attenuation (dB) | 0.029 | 0.761 | 4.405 | 9.511 |
|  | 47 | Atmospheric + rain noise temperature (K) | 1.880 | 45.021 | 178.454 | 248.666 |
|  | 48 | Background noise temperature (K) | 5.190 | 2.074 | 0.815 | 0.228 |
|  | 49 | Noise temperature (K) | 7.071 | 47.095 | 179.27 | 248.894 |
|  | 50 | Noise power spectral density (dB(W/Hz)) | −220.11 | −211.87 | −206.06 | −204.64 |

# 8 Link performance for atmospheric attenuation

Table 4 presents link performance calculated for an assumed set of equipment and distance parameters, using the attenuation and noise temperature values for propagation under the condition of atmosphere only. Referring to the line numbers given at the left side of the table, the calculations are made as follows:

Line 9 Frequency (GHz)

Radio frequency for which the calculation is made.

Line 11 Spacecraft transmit power *P*0 (dBW)

Assumed spacecraft transponder power, in this case 25 W, given by:

*P*0  10 log 25 dBW

Line 12 Gain, 3.7 m diameter (dBi)

Assumed gain of the spacecraft transmitting antenna, in this case a 3.7 m diameter parabola with assumed 100% efficiency, given by:

20.40 + 20 log(diameter(m))  20 log(frequency(GHz))          dBi

Line 13 Free space loss (dB)

Attenuation for a free space path, in this case for a path length of 800 x 106 km, given by Recommendation ITU-R P.525-2:

32.4 + 20 log(frequency(MHz)) + 20 log(path(km)) =

270.51  20 log(frequency(GHz))          dB

Line 14 Gain, 70 m diameter (dBi)

Gain of the earth station receiving antenna, in this case a 70 m diameter parabola with assumed 100% efficiency, given by:

20.40 + 20 log(diameter(m))  20 log(frequency(GHz))          dBi

Line 16 Elevation angle 15 (degrees)

Elevation angle of the earth station receiving antenna and propagation path through the atmosphere, in this case 15°.

Line 17 Atmospheric attenuation (dB)

Attenuation due to the atmosphere at the specified elevation angle taken from Table 1.

Line 18 Received signal power (dBW)

Power received at the terminals of the earth station antenna given by:

Line 11  Line 12 – Line 13  Line 14 – Line 17

Line 19 System noise power spectral density (dB(W/Hz))

Received noise power spectral density taken from Table 1. For the example presented by Table 4, the noise temperature contribution of the earth station receiving system has been assumed to be zero.

Line 20  (dBHz)

Ratio of received power to noise power spectral density given by line 18 and line 19. The variation of *Pr*/*N*0 with frequency provides the basis for selection of preferred frequency bands in terms of link performance. Frequencies with highest *Pr*/*N*0 provide the best performance for a given set of assumed conditions and equipment characteristics.

Lines 22-26 and 28-32 are similar to lines 16-20 except for different values of elevation angles.

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| 1 | TABLE 4 | | | | |
| 2 | Data for selection of preferred frequencies  Ideal link performance, space-to-Earth, atmosphere, no rain | | | | |
| 3 |  | | | | |
| 4 |  | | | | |
| 5 |  | | | | |
| 6 |  | | | | |
| 7 | ------------------------------------------------------------------------------------------------------------------------------------ | | | | |
| 8 |  |  |  |  |  |
| 9 | Frequency (GHz) | 1 | 10 | 20 | 30 |
| 10 |  |  |  |  |  |
| 11 | Spacecraft transmit power *P*0 (dBW) | 13.98 | 13.98 | 13.98 | 13.98 |
| 12 | 3.7 m antenna gain (dBi) | 31.76 | 51.77 | 57.79 | 61.31 |
| 13 | Free space loss (dB) | 270.50 | 290.50 | 296.52 | 300.05 |
| 14 | 70 m antenna gain (dBi) | 57.30 | 77.30 | 83.32 | 86.84 |
| 15 |  |  |  |  |  |
| 16 | Elevation angle (degrees) | 15 |  |  |  |
| 17 | Atmospheric attenuation (dB) | 0.109 | 0.202 | 0.989 | 0.932 |
| 18 | Received signal power (dBW) | –167.57 | –147.66 | –142.43 | –138.85 |
| 19 | System noise power spectral density (dB(W/Hz)) | −217.80 | –216.82 | –210.90 | –211.14 |
| 20 | *Pr*/*N*0 (dBHz) | 50.24 | 69.16 | 68.48 | 72.29 |
| 21 |  |  |  |  |  |
| 22 | Elevation angle (degrees) | 30 |  |  |  |
| 23 | Atmospheric attenuation (dB) | 0.056 | 0.104 | 0.512 | 0.482 |
| 24 | Received signal power (dBW) | –167.51 | –147.56 | –141.95 | –138.40 |
| 25 | System noise power spectral density (dB(W/Hz) | –219.17 | –219.02 | –213.40 | –213.65 |
| 26 | *Pr*/*N*0 (dBHz) | 51.66 | 71.46 | 71.45 | 75.25 |
| 27 |  |  |  |  |  |
| 28 | Elevation angle (degrees) | 75 |  |  |  |
| 29 | Atmospheric attenuation (dB) | 0.029 | 0.054 | 0.265 | 0.250 |
| 30 | Received signal power (dBW) | –167.49 | –147.51 | –141.70 | –138.16 |
| 31 | System noise power spectral density (dB(W/Hz)) | –220.11 | –220.89 | –215.88 | –216.15 |
| 32 | *Pr*/*N*0 (dBHz) | 52.62 | 73.38 | 74.18 | 77.99 |

# 9 Link performance for atmosphere plus rain attenuation

The calculation of link performance for atmosphere plus rain is shown in Table 5. Tables 4 and 5 are similar except that in Table 5 the values of attenuation and noise temperature are taken in part from Table 3. Also note that Table 5 includes the frequency dependent effects of earth station hardware: the variation in antenna gain, and the contributions to total noise.

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
|  | 1 | TABLE 5 | | | | |
|  | 2 | Data for selection of preferred frequencies  Achievable link performance, space-to-Earth, atmosphere plus rain, includes effects of earth station hardware | | | | |
|  | 3 |  | | | | |
|  | 4 |  | | | | |
|  | 5 |  | | | | |
|  | 6 |  | | | | |
|  | 7 | ----------------------------------------------------------------------------------------------------------------------------------------------------- | | | | |
|  | 8 |  |  |  |  |  |
|  | 9 | Frequency (GHz) | 1 | 10 | 20 | 30 |
|  | 10 |  |  |  |  |  |
|  | 11 | Spacecraft transmit power *P*0 (dBW) | 13.98 | 13.98 | 13.98 | 13.98 |
|  | 12 | 3.7 m antenna gain (dBi) | 29.55 | 49.55 | 55.57 | 59.09 |
|  | 13 | Free space loss (dB) | 270.50 | 290.50 | 296.52 | 300.05 |
|  | 14 |  |  |  |  |  |
|  | 15 |  |  |  |  |  |
|  | 16 | Elevation angle (degrees) | 15 | 15 | 15 | 15 |
|  | 17 | 70 m antenna gain (dBi) | 55.23 | 74.91 | 79.96 | 81.86 |
|  | 18 | Atmosphere + rain attenuation (dB) | 0.109 | 2.060 | 9.313 | 17.576 |
|  | 19 | Received signal power (dBW) | −171.84 | −154.11 | −156.32 | −162.69 |
|  | 20 | Background noise temperature (K) | 5.095 | 1.538 | 0.263 | 0.035 |
|  | 21 | Atmospheric noise temperature with rain (K) | 6.953 | 105.75 | 247.20 | 275.107 |
|  | 22 | Receiver noise temperature (K) | 14.6 | 20 | 26 | 32 |
|  | 23 | System noise temperature (K) | 26.6 | 127.3 | 273.47 | 307.1 |
|  | 24 | System noise power spectral density (dBW/Hz) | −214.35 | −207.55 | −204.23 | −203.73 |
|  | *25* | *Pr*/*N*0 (dBHz) | 42.5 | 53.43 | 47.91 | 41.04 |
|  | 26 |  |  |  |  |  |
|  | 27 |  |  |  |  |  |
|  | 28 | Elevation angle (degrees) | 30 | 30 | 30 | 30 |
|  | 29 | 70 m antenna gain (dBi) | 55.61 | 75.30 | 80.341 | 82.24 |
|  | 30 | Atmosphere + rain attenuation (dB) | 0.056 | 1.265 | 6.089 | 11.959 |
|  | 31 | Received signal power (dBW) | −171.41 | −152.94 | −152.72 | −156.69 |
|  | 32 | Background noise temperature (K) | 5.158 | 1.847 | 0.553 | 0.130 |
|  | 33 | Atmospheric noise temperature with rain (K) | 3.621 | 70.772 | 211.05 | 262.166 |
|  | 34 | Receiver noise temperature (K) | 12.9 | 18.3 | 24.3 | 30.3 |
|  | 35 | System noise temperature (K) | 21.7 | 90.9 | 235.86 | 292.6 |
|  | 36 | System noise power spectral density (dB W/Hz) | −215.24 | −209.01 | −204.87 | −203.94 |
|  | 37 | *Pr*/*N*0 (dBHz) | 43.84 | 56.07 | 52.2 | 47.25 |
|  | 38 |  |  |  |  |  |
|  | 39 |  |  |  |  |  |
|  | 40 | Elevation angle (degrees) | 75 | 75 | 75 | 75 |
|  | 41 | 70 m antenna gain (dBi) | 55.27 | 74.95 | 80.00 | 81.89 |
|  | 42 | Atmosphere + rain attenuation (dB) | 0.029 | 0.761 | 4.405 | 9.511 |
|  | 43 | Received signal power (dBW) | −171.72 | −152.78 | −151.38 | −154.59 |
|  | 44 | Background noise temperature (K) | 5.190 | 2.074 | 0.815 | 0.228 |
|  | 45 | Atmospheric noise temperature with rain (K) | 1.880 | 45.021 | 178.454 | 248.666 |
|  | 46 | Receiver noise temperature (K) | 12.1 | 17.5 | 23.5 | 29.5 |
|  | 47 | System noise temperature (K) | 19.1 | 64.6 | 202.7 | 278.4 |
|  | 48 | System noise power spectral density (dB(W/Hz)) | −215.77 | −210.50 | −205.53 | −204.15 |
|  | 49 | *Pr*/*N*0 (dB(Hz) | 44.05 | 57.72 | 54.15 | 49.57 |

# 10 Conclusion

The method presented in this report is recommended to be used to calculate link performance in the space research service. This method provides a ratio of received power to noise power spectral density, *Pr*/*N*0. The variation of *Pr*/*N*0 with frequency provides the basis for selection of preferred frequency bands. Frequencies with the highest *Pr*/*N*0 provide the best performance for a given set of assumed conditions and equipment characteristics. The preferred frequency bands are identified within approximately 1 dB of the maximum available *Pr*/*N*0 value.

By considering the performance of currently realizable links as well as ideal links, it is possible to identify preferred frequency bands for the present time and also for the future when equipment is further improved.

An example using this method to calculate performance achievable with different equipment characteristics is given in Fig. 1. The figure shows two sets of curves for a space-to-Earth path.

In the first set, the equipment is assumed to be perfect. The antennas are assumed to be ideal with gain that varies as the square of the frequency or with a beamwidth (gain) that is constant with respect to frequency. The transmitter power is assumed constant with respect to frequency and the noise temperature of the receiving system equipment is neglected. The purpose of these assumptions is to allow selection of preferred frequency bands as limited only by natural phenomena.

The second set of curves includes the frequency dependent variations of a particular set of equipment parameters. Some parameters of the earth station antenna also depend upon elevation angles, and these variations are included. Factors considered include antenna gain variation as a function of elevation angle; the noise temperature contribution of the warm Earth as coupled via the feed support structure and illumination spillover; and receiver equipment noise temperature. The purpose of including these factors is to allow selection of preferred frequency bands for a link that includes the characteristics of practical equipment.

Figure 1

Space-to-Earth link performance, *Pr*/*N*0



The preferred frequency bands can be identified from Fig. 1 as 11.5-19 GHz for the atmosphere only case, and 4-7 GHz for the atmosphere plus rain case.