RECOMMENDATION ITU-R SA.1017*

Preferred method for calculating link performance in the space research service

(Question ITU-R 131/7)

(1994)

The ITU Radiocommunication Assembly,

considering

a) that the identification of frequency ranges that provide highest link performance is useful in connection with providing a basis for band allocations and for other frequency management purposes;

b) that link performance calculations necessarily involve consideration of the characteristics of radio wave propagation;

c) that Recommendations on propagation provide equations, algorithms and data suitable for making such calculations;

d) that a method of making the calculations, based on these Recommendations has been developed for studies of preferred frequency bands for the space research service;

e) that Annex 1 presents this method;

f) that the method also takes into account noise and attenuation factors that are particularly applicable to some systems having noise temperatures less than approximately 30 K,

recommends

1 that the method given in Annex 1 be considered a preferred method for use when link performance calculations for the space research service are to be made on the basis of ITU-R Recommendations on propagation.

Annex 1

Method of using ITU-R propagation information for calculations of attenuation, noise temperature and link performance

1 Introduction

This Annex 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.

* Radiocommunication Study Group 7 made editorial amendments to this Recommendation in 2003 in accordance with Resolution ITU-R 44.

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: Characteristics of precipitation for propagation modelling

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

Recommendation ITU-R P.676: Attenuation by atmospheric gases

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

Recommendation ITU-R P.372: Radio noise.

3 Calculation procedures

A step by step discussion of the calculations needed in order to determine the variation of link performance with frequency is given in Appendix 1. For convenience in presenting the method, and for conceptual clarity, the calculations are grouped into five sections:

– calculations of attenuation and noise temperature for clear air (no rain or clouds),

– calculation of the effects of rain attenuation and noise temperature,

– calculations of attenuation and noise temperature for clear air plus rain,

– calculations of link performance for clear air (no rain or clouds),

– calculation of link performance for clear air plus rain.

NOTE 1 – 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.

4 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 beamwidth 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 manoeuvres or loss of attitude control.

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

5 Selection of preferred frequency bands

The calculations may be used to create two sets of link performance curves. 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 angle, 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.

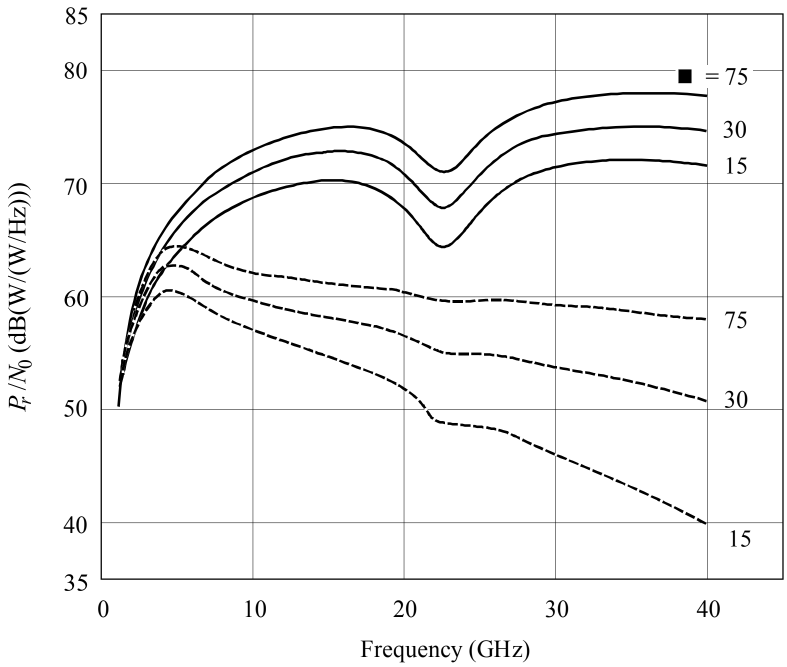
By considering the performance of currently realizable links as well as ideal links, it is possible to identify preferred frequency bands for the present time and also for the future when equipment is further improved.

An example of the performance achievable with ideal equipment is given in Fig. 1. The Figure shows curves for a space-to-Earth path. Perfect equipment is assumed, including fixed diameter antennas for transmitting and receiving. If it is desired to identify a frequency band in the 1-40 GHz range that yields performance within approximatively 1 dB of the maximum available, the curves give the following results, for the case of 30° elevation angle:

Propagation condition	Preferred frequency band
Clear air (no rain or clouds)	12.5-19.2 GHz
Clear air plus 0.1 % rain	4 100-9 400 MHz

FIGURE 1

Space-to-Earth link performance, P_r/N_0



Fixed diameter earth station and space station antennas
Ideal link performance as limited by natural phenomena only

———— Clear atmosphere, 7.5 gm/m^3 water vapour

- - - - - - Atmosphere plus rain, 10 mm/h

■ Elevation angle (degrees) of earth station antenna

D01

Appendix 1
to Annex 1

Calculation procedure

1 Introduction

The calculation of space-to-Earth link performance under conditions of clear air and clear air plus rain is described. Tables 1 to 5 list the several parameters included in the calculation. The Tables are:

1) Attenuation and noise temperature as a function of frequency, elevation angle and water vapour density for clear air 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 clear air 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.

NOTE 1 – 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 each line in each table there is a description of the parameter or calculation and, usually, a particular information source is referenced.

2 Calculations for clear air (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 clear air (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 Vapour density (gm/m^3)

Water vapour density in the atmosphere that is assumed for the particular calculation.

Line 8 Station elevation (km)

Elevation 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 *Ho′* (km)

Equivalent oxygen height at the earth station elevation. *Ho′* is derived from a correction to the value of *Ho*, the equivalent oxygen height at sea level, and for frequencies < 57 GHz is given by:

$$Ho \times e^{(-\text{station elevation} / Ho)} \qquad \text{km}$$

where Ho = 6 km at sea level.

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

Line 13 Ogamma (dB/km)

Specific attenuation at ground level due to oxygen at a temperature of 15° C, and for frequencies <57 GHz is given by:

$$\left(7.19 \times 10^{-3} + \frac{6.09}{f^2 + 0.227} + \frac{4.81}{(f - 0.57)^2 + 1.5}\, f^2 \times 10^{-3}\right) \qquad \text{dB/km}$$

See § 1, Recommendation ITU-R P.676.

Line 14 *Hw′* (km)

Equivalent water vapour height at the earth station elevation. *Hw′* is derived from a correction to the value of *Hw*, the equivalent water vapour height at sea level. The nature of the correction is such that for a path between an earth station and a satellite, $Hw' = Hw$. For frequencies < 350 GHz, *Hw* is given by:

$$Hw_0 \left(1 + \frac{3}{(f - 22.2)^2 + 5} + \frac{5}{(f - 183.3)^2 + 6} + \frac{2.5}{(f - 325.4)^2 + 4}\right) \qquad \text{km}$$

where Hw_0 = 1.6 km in clear weather and 2.1 km in rain.

NOTE 1 – For frequencies less than 57 GHz, only the first two terms of the expression are needed.

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

Line 15 Wgamma (dB/km)

Specific attenuation at ground level due to water vapour at a temperature of 15° C, ρ < 12 gm/m^3, and frequencies < 350 GHz given by:

$$\left[0.05 + 0.0021\,\rho + \frac{3.6}{(f - 22.2)^2 + 8.5} + \frac{10.6}{(f - 183.3)^2 + 9} + \frac{8.9}{(f - 325.4)^2 + 26.3}\right] f^2 \times \rho \times 10^{-4} \qquad \text{dB/km}$$

where ρ is the water density (gm/m^3) at the station elevation.

NOTE 1 – For frequencies less than 57 GHz, only the first two terms of the expression between brackets are needed.

See § 1, Recommendation ITU-R P.676.

Line 17 Galactic temp @ 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.

Line 18 Galactic temp (K)

Temperature calculated for a particular frequency, given by:

$$\text{(Galactic temp @ 408 MHz)} \left(\frac{\text{Frequency (MHz)}}{408}\right)^{-2.75} \qquad \text{K}$$

See § 4, Recommendation ITU-R P.372.

Line 19 Cosmic noise (W/Hz)

Power spectral density of the cosmic background noise given by:

$$\frac{hf}{e^{(hf/kT)} - 1} \qquad \text{W/Hz}$$

where:

$h = 6.626 \times 10^{(-34)}$ (J/s) (Planck's constant)

f: frequency (Hz)

$k = 1.3806 \times 10^{(-23)}$ (J/K) (Boltzmann's constant)

T: noise temperature, taken as 2.7 K.

Line 20 Cosmic temp (K)

Cosmic background noise temperature, given by:

$$\text{Cosmic noise} / k \qquad \text{K}$$

where k is Boltzmann's constant, 1.3806×10^{-23} (J/K).

Line 21 Cosmic + galactic (K)

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

$$\text{Cosmic temp} + \text{Galactic temp} \qquad \text{K}$$

Line 23 Zenith attn (dB)

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

$$(Ho' \times \text{Ogamma}) + (Hw' \times \text{Wgamma}) \qquad \text{dB}$$

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

Line 24 Zenith atmos noise (K)

Noise temperature caused by the atmosphere in the zenith direction given by:

$$280\,(1 - 10^{-A(\text{dB})/10}) \qquad \text{K}$$

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 Recommendation ITU-R P.372.

Line 25 Zenith cosmic + galactic (K)

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

$$(\text{Cosmic} + \text{galactic}) / \text{e}^{A(\text{dB})/4.34}) \qquad \text{K}$$

See Recommendation ITU-R P.372.

Line 26 Zenith total noise (K)

Sum of the zenith atmospheric noise temperature, and the zenith cosmic + galactic noise temperature, given by:

$$\text{Zenith atmos noise} + \text{zenith (cosmic} + \text{galactic)} \qquad \text{K}$$

Line 29 Elev angle (degrees)

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

Line 30 Elev atmos attn (dB)

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

$$\text{Zenith attenuation} / \sin \text{(elevation angle)} \qquad \text{dB}$$

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

Line 31 Elev atmos noise (K)

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

$$280\,(1 - 10^{B(\text{dB})/10}) \qquad \text{K}$$

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 Elev cosmic + galactic (K)

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

$$(\text{Cosmic} + \text{galactic}) / \text{e}^{B(\text{dB})/4.34}) \qquad \text{K}$$

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

Line 33 Elev total noise (K)

Sum of the atmospheric noise and the cosmic + galactic noise at the particular elevation angle, given by:

$$\text{Elev atmos noise} + \text{elev cosmic} + \text{galactic elev} \qquad \text{K}$$

Line 34 Elev noise (dB(W/Hz))

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

$$-228.6 + 10 \log \text{(elev total noise)} \qquad \text{dB(W/Hz)}$$

where –228.6 is the logarithmic expression of Boltzmann'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 or preferred frequencies**
Attenuation and noise temperature, clear air, no rain

3					
4					
5					
6	------------------------------------				
7	Vapour density (gm/m^{3})	7.5			
8	Station elevation (km)	0.81			
9					
10	Frequency (GHz)	1	10	20	30
11					
12	*Ho′* (km)	5.242	5.242	5.242	5.242
13	Ogamma (dB/km)	0.005	0.007	0.010	0.018
14	*Hw′* (km)	1.611	1.632	2.088	1.673
15	Wgamma (dB/km)	0.000	0.007	0.101	0.080
16					
17	Galactic temp @ 408 MHz (K)	30			
18	Galactic temp (K)	2.549	0.005	0.001	0.000
19	Cosmic noise (W/Hz)	3.69E-23	3.41E-23	3.10E-23	2.82E-23
20	Cosmic temp (K)	2.676	2.467	2.248	2.044
21	Cosmic + galactic (K)	5.225	2.472	2.249	2.044
22					
23	Zenith attn (dB)	0.03	0.05	0.26	0.23
24	Zenith atmos noise (K)	1.68	3.06	16.57	14.47
25	Zenith cosmic + galactic (K)	5.19	2.44	2.12	1.94
26	Zenith total noise (K)	6.88	5.50	18.68	16.41
27					
28					
29	Elev angle (degrees)	15.00			
30	Elev atmos attn (dB)	0.10	0.18	1.02	0.89
31	Elev atmos noise (K)	6.44	11.62	58.79	51.90
32	Elev cosmic + galactic (K)	5.11	2.37	1.78	1.66
33	Elev total noise (K)	11.55	13.99	60.56	53.56
34	Elev noise power (dB(W/Hz))	–217.98	–217.14	–210.78	–211.31
35					
36					
37	Elev angle (degrees)	30.00			
38	Elev atmos attn (dB)	0.05	0.10	0.53	0.46
39	Elev atmos noise (K)	3.35	6.08	32.16	28.19
40	Elev cosmic + galactic (K)	5.16	2.42	1.99	1.84
41	Elev total noise (K)	8.52	8.50	34.15	30.03
42	Elev noise power (dB(W/Hz))	–219.30	–219.31	–213.27	–213.82
43					
44					
45	Elev angle (degrees)	75.00			
46	Elev atmos attn (dB)	0.03	0.05	0.27	0.24
47	Elev atmos noise (K)	1.74	3.16	17.13	14.97
48	Elev cosmic + galactic (K)	5.19	2.44	2.11	1.93
49	Elev total noise (K)	6.93	5.61	19.25	16.90
50	Elev noise power (dB(W/Hz))	–220.19	–221.11	–215.76	–216.32

3 Calculation of the effects of rain

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 7 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 8 Station elevation (km)

Elevation of the earth station above sea level: 0.81 km for Madrid, Spain.

Line 9 Rain rate (mm/h)

Rain rate exceeded 0.01% of the year, and for this example is 32 mm/h for Madrid, Spain (rain climate H).

See § 2.2.1.1, Step 5, Recommendation ITU-R P.618 and Fig. 1 and Table 1, Recommendation ITU-R P.837.

Line 10 Rain height (km) is given by:

$$3.0 + 0.028 \text{ lat} \quad \text{for} \quad 0° < \text{lat} < 36°$$

$$4.0 - 0.075 (\text{lat} - 36) \quad \text{for} \quad \text{lat} \geq 36°$$

where lat is the latitude of the earth station.

See § 2.2.1.1, Step 1, Recommendation ITU-R P.618.

Line 12 Frequency (GHz)

Line 14 Coeff *kH*

Coefficient used for estimating specific attenuation due to rain.

See Recommendation ITU-R P.838.

For values of *kH* not given directly in the table, the formula for interpolation is:

$$\log kH = \left(\frac{\log f - \log f_1}{\log f_2 - \log f_1} \right) (\log kH_2 - \log kH_1) + \log kH_1$$

where the numbers 2 and 1 refer to the higher and lower tabulated values between which the unknown value lies.

Line 15 Coeff *aH*

Coefficient used for estimating specific attenuation due to rain.

See Recommendation ITU-R P.838.

For values of *aH* not given directly in the table, the formula for interpolation is:

$$aH = \left(\frac{\log f - \log f_2}{\log f_2 - \log f_1} \right) (aH_2 - aH_1) + aH_1$$

where the numbers 2 and 1 refer to the higher and lower tabulated values between which the unknown value lies.

Line 16 rGamma (dB/km)

Specific attenuation due to rain given by:

$$kH \times \text{Rain rate}^{(aH)} \qquad \text{dB/km}$$

See Recommendation ITU-R P.838 and Step 6, Recommendation ITU-R P.618.

Line 19 Elevation angle (degrees).

Line 20 Slant path (km)

Length of the slant path through the rain from the earth station to the rain height, and is given by:

$$(\text{Rain height} - \text{station elevation}) / \sin(\text{elevation angle}) \qquad \text{km}$$

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

Line 21 Horiz proj (km)

Horizontal projection of the slant path, given by:

$$\text{Slant path} \times \cos(\text{elevation angle}) \qquad \text{km}$$

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

Line 22 Reduction 0.01%

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

$$\frac{1}{1 + (0.05 \ \text{horizontal projection})}$$

See § 2.2.1.1, Step 4, Recommendation ITU-R P.618.

Line 24 Atten 0.01% (dB)

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

$$\text{rGamma} \times \text{slant path} \times \text{reduction}(0.01\%) \qquad \text{dB}$$

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

Line 25 Atten 0.1% (dB)

Rain attenuation exceeded 0.1% of the year, and is given by:

$$0.38 \ \text{atten}(0.1\%) \qquad \text{dB}$$

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, Step 8, Recommendation ITU-R P.618.

Lines 28-34 and 37-43 are similar to lines 19-25 except for the effects of different elevation angles.

TABLE 2

Data for selection or preferred frequencies
Attentuation caused by rainfall alone, without atmosphere

Station latitude (degrees)	40			
Station elevation (km)	0.81			
Rain rate (mm/h) 0.01%	32			
Rain height (km)	3.7			
Frequency (GHz)	1	10	20	30
Coeff *kH*	3.87E-05	1.01E-02	7.51E-02	1.87E-01
Coeff *aH*	0.912	1.276	1.099	1.021
rGamma (dB/km)	9.13E-04	8.41E-01	3.39E+00	6.44E+00
Elevation angle (degrees)	15			
Slant path (km)	11.17			
Horiz proj (km)	10.79			
Reduction 0.01%	0.67			
Atten 0.01% (dB)	0.007	6.324	25.462	48.383
Atten 0.1% (dB)	0.003	2.466	9.930	18.869
Elev angle (degrees)	30			
Slant path (km)	5.78			
Horiz proj (km)	5.01			
Reduction 0.01%	0.82			
Atten 0.01% (dB)	0.004	3.968	15.978	30.362
Atten 0.1% (dB)	0.002	1.548	6.231	11.841
Elev angle (degrees)	75			
Slant path (km)	2.99			
Horiz proj (km)	0.77			
Reduction 0.01%	0.97			
Atten 0.01% (dB)	0.003	2.432	9.792	18.607
Atten 0.1% (dB)	0.001	0.949	3.819	7.257

4 Calculations for clear air plus rain

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 clear air and rain. Referring to the line numbers given at the left side of the table, the calculations are made as follows:

Lines 1 through 30 are as explained for Table 1.

Line 31 Elev rain attn (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 32 Elev total attn (dB)

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

Line 33 Elev atmos + rain noise (K)

Noise temperature due to the elevation total attenuation, given by:

$$280\,(1 - 10^{-B/10}) \qquad \text{K}$$

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

Line 34 Elev cosmic + galactic (K)

Sum of the cosmic noise temperature and the galactic noise temperature, as reduced by the attenuation along the path at the particular elevation angle (see Line 19, Table 1).

Line 35 Elev total noise (K)

Sum of the atmospheric and rain noise and the cosmic + galactic noise for the particular elevation angle.

Line 36 Elev noise power (dB(W/Hz))

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

$$-228.6 + 10 \log (\text{elev total noise (K)}) \qquad \text{dB(W/Hz)}$$

where –228.6 is the logarithmic expression of Boltzmann's constant, 1.3806×10^{-23} (J/K).

Lines 39-46 are similar to lines 29-36 except for the effects of different elevation angles.

TABLE 3

Data for selection or preferred frequencies
Attentuation and noise temperature, clear air plus rain

Vapour density (gm/m^3)	7.50			
Station elevation (km)	0.81			
Frequency (GHz)	1	10	20	30
Ho′ (km)	5.242	5.242	5.242	5.242
Ogamma (dB/km)	0.005	0.007	0.010	0.018
Hw′ (km)	2.114	2.141	2.741	2.196
Wgamma (dB/km)	0.000	0.006	0.081	0.076
Galactic temp @ 408 MHz (K)	30			
Galactic temp (K)	2.549	0.005	0.001	0.000
Cosmic noise (W/Hz)	3.69E-23	3.41E-23	3.10E-23	2.82E-23
Cosmic temp (K)	2.676	2.467	2.248	2.044
Cosmic + galactic (K)	5.225	2.472	2.249	2.044
Zenith attn (dB)	0.03	0.05	0.28	0.26
Zenith atmos noise (K)	1.68	3.23	17.24	16.51
Zenith cosmic + galactic (K)	5.19	2.44	2.11	1.92
Zenith total noise (K)	6.88	5.67	19.35	18.43
Elev angle (degrees)	15.00			
Elev atmos attn (dB)	0.10	0.19	1.07	1.02
Elev rain attn (dB)	0.00	2.47	9.93	18.87
Elev total attn dB	0.10	2.66	11.00	19.89
Elev atmos + rain noise (K)	6.61	128.27	257.74	277.13
Elev cosmic + galactic (K)	5.10	1.34	0.18	0.02
Elev total noise (K)	11.72	129.60	257.92	277.15
Elev noise power (dB(W/Hz))	–217.91	–207.47	–204.49	–204.17
Elev angle (degrees)	30.00			
Elev atmos attn (dB)	0.05	0.10	0.55	0.53
Elev rain attn (dB)	0.00	1.55	6.23	11.84
Elev total attn (dB)	0.05	1.65	6.78	12.37
Elev atm + rain noise (K)	3.46	88.43	221.28	263.77
Elev cosmic + galactic (K)	5.16	1.69	0.47	0.12
Elev total noise K	8.62	90.12	221.75	263.89
Elev noise power (dB(W/Hz))	–219.24	–209.05	–205.14	–204.39

5 Link performance for clear air

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 conditions of clear air. 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 power P_0 (dBW)

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

$$P_0 = 10 \log 25$$

Line 12 Gain, 3.7 m diam (dBi)

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

$$20.40 + 20 \log (\text{diameter (m)}) + 20 \log (\text{frequency (GHz)}) \qquad \text{dBi}$$

Line 13 Free space loss (dB)

Attenuation for a free space path, in this case for a path length of 8 x 10^6 km, given by:

$$230.51 + 20 \log (\text{frequency (GHz)}) \qquad \text{dB}$$

Line 14 Gain, 70 m diam (dBi)

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

$$20.40 + 20 \log (\text{diameter (m)}) + 20 \log (\text{frequency (GHz)}) \qquad \text{dBi}$$

Line 16 Elev angle 15 (degrees)

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

Line 17 Atmos attn (dB)

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

Line 18 Received power (dBW)

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

$$\text{Line 11} + \text{Line 12} - \text{Line 13} + \text{Line 14} - \text{Line 17}$$

Line 19 Noise power (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 P_r/N_0 (dB(W/(W/Hz))) (often expressed as dBHz)

Ratio of received power to noise power spectral density given by (line 18, line 19). The variation of P_r/N_0 with frequency provides the basis for selection of preferred frequency bands in terms of link performance. Frequencies with highest P_r/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 angle.

1 TABLE 4

2 **Data for selection of preferred frequencies**
Ideal link performance, space-to-Earth, clear air, no rain

3					
4					
5					
6					
7					
8					
9	Frequency (GHz)	1	10	20	30
10					
11	Spacecraft power P_0 (dBW)	13.98			
12	Gain, 3.7 m diam (dBi)	31.77	51.77	57.79	61.31
13	Free space loss (dB)	270.51	290.51	296.53	300.05
14	Gain, 70 m diam (dBi)	57.30	77.30	83.32	86.84
15					
16	Elev angle (degrees)	15			
17	Atmos attn (dB)	0.10	0.18	1.02	0.89
18	Received power (dBW)	–167.56	–147.64	–142.46	–138.81
19	Noise power (dB(W/Hz))	–217.98	–217.14	–210.78	–211.31
20	P_r/N_0 (dB(W/(W/Hz)))	50.41	69.50	68.31	72.50
21					
22	Elev angle (degrees)	30			
23	Atmos attn (dB)	0.05	0.10	0.53	0.46
24	Received power (dBW)	–167.51	–147.56	–141.97	–138.38
25	Noise power (dB(W/Hz)	–219.30	–219.31	–213.27	–213.82
26	P_r/N_0 (dB(W/(W/Hz)))	51.79	71.75	71.30	75.45
27					
28	Elev angle (degrees)	75			
29	Atmos attn (dB)	0.03	0.05	0.27	0.24
30	Received power (dBW)	–167.49	–147.51	–141.71	–138.16
31	Noise power (dB(W/Hz))	–220.19	–221.11	–215.76	–216.32
32	P_r/N_0 (dB(W/(W/Hz)))	52.70	73.60	74.04	78.16

6 Link performance for clear air plus rain

The calculation of link performance for clear air 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 power.

TABLE 5

Data for selection or preferred frequencies
Achievable link performance, space-to-Earth, clear air plus rain
Includes effects of earth station hardware

Frequency (GHz)	1	10	20	30
Spacecraft power P_0 (dBW)	13.98			
Gain, 3.7 m diam (dBi)	29.55	49.55	55.57	59.09
Free space loss (dB)	270.51	290.51	296.53	300.05
Elev angle (degrees)	15			
70 m gain (dBi)	55.67	75.35	80.40	82.30
Atmos attn (dB)	0.10	0.18	1.02	0.89
Received power (dBW)	–171.41	–151.81	–147.60	–145.57
Sky noise (K)	11.55	13.99	60.56	53.56
DSN* noise (K)	10.01	16.13	20.97	26.16
Station noise (K)	–215.26	–213.81	–209.49	–209.58
P_r/N_0 (dB)	43.85	62.00	61.88	64.02
Elev angle (degrees)	30			
70 m gain (dBi)	55.67	75.42	80.69	82.95
Atmos attn (dB)	0.05	0.10	0.53	0.46
Received power (dBW)	–171.36	–151.65	–146.82	–144.49
Sky noise (K)	8.52	8.50	34.15	30.03
Station noise (K)	8.71	14.83	19.67	24.86
Noise power (dB(W/Hz)) (kTB)	–216.24	–214.92	–211.29	–211.21
P_r/N_0 (dB)	44.88	63.27	64.47	66.72
		–214.97	–211.33	–211.26
Elev angle (degrees)	75			
70 m diam (dBi)	55.67	75.32	80.29	82.06
Atmos attn (dB)	0.03	0.05	0.27	0.24
Received power (dBW)	–171.34	–151.71	–146.96	–145.15
Sky noise (K)	6.93	5.61	19.25	16.90
Station noise (K)	6.41	12.53	17.37	22.56
Noise power (dB(W/Hz))	–217.35	–216.01	–212.96	–212.64
P_r/N_0 (dB(W/(W/Hz)))	46.01	64.31	66.00	67.49

*DSN: deep space network