RECOMMENDATION ITU-R F.1404*

MINIMUM PROPAGATION ATTENUATION DUE TO ATMOSPHERIC GASES FOR USE IN FREQUENCY SHARING STUDIES BETWEEN SYSTEMS IN THE FIXED SERVICE AND SYSTEMS IN THE BROADCASTING-SATELLITE, MOBILE-SATELLITE AND SPACE SCIENCE SERVICES

(Questions ITU-R 111/9, ITU-R 113/9 and ITU-R 163/9)

(1999)

The ITU Radiocommunication Assembly,

considering

a) that slant path attenuation between a terrestrial station and a space station (geostationary (GSO) or non-geostationary (non-GSO)) resulting from absorption due to atmospheric gases including water vapour is an important factor in frequency sharing studies between systems in the fixed service (FS) and systems in the broadcasting-satellite service (BSS), the mobile-satellite service (MSS) and space science service;

b) that slant path attenuation depends on the distribution along the path of meteorological parameters such as temperature, pressure and humidity, and thus varies with the geographic location of the site, the month of the year, the height of an FS station above sea level and the elevation angle of the slant path;

c) that such slant path attenuation can be estimated by the method described in Annex 1 to Recommendation ITU-R P.676, but that it is desirable to provide a simple procedure to estimate the attenuation;

d) that for the purpose of frequency sharing studies, it is necessary to define the parameters in the driest month at sea level for each climate area, based on Recommendation ITU-R P.835;

e) that slant path attenuation is a complicated function of the frequency and that for each frequency band a representative frequency giving the lowest attenuation should be chosen,

recommends

1 that for frequency sharing studies between FS systems and BSS, MSS and space science service systems in each frequency band, slant path attenuation resulting from absorption due to atmospheric gases including water vapour should be estimated at a representative frequency which gives the lowest attenuation in that band (see Note 1);

2 that the method of Annex 1 should be utilized for the estimation of slant path attenuation due to atmospheric absorption (see Notes 2, 3 and 4).

NOTE 1 - The information in this Recommendation is solely for the purpose of frequency sharing studies, because it deals with the slant path attenuation in the driest month.

NOTE 2 - When more details are required, these may be obtained from Recommendation ITU-R P.676.

NOTE 3 - The information in this Recommendation is based on Recommendation ITU-R P.676-3 (Geneva, 1997) and Recommendation ITU-R P.835-2 (Geneva, 1997).

NOTE 4 - Recommendation ITU-R SF.1395 presents approximate formulae of minimum slant path attenuation due to atmospheric absorption for the frequency bands shared by the FS and the FSS.

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* This Recommendation should be brought to the attention of Radiocommunication Study Groups 3 (Working Party 3J), 7 (Working Party 7D), 8 (Working Party 8D), 10 and 11 (Joint Working Party 10-11S).

ANNEX 1

Estimation of slant path propagation attenuation due to atmospheric gases for use in frequency sharing studies between FS systems and BSS, MSS and space science service systems

1 Introduction

Slant path attenuation between a terrestrial station and a space station (GSO or non-GSO) resulting from absorption due to atmospheric gases including water vapour is an important factor in frequency sharing studies between FS systems and BSS, MSS and space science service systems. The slant path attenuation depends on the distribution along the path of meteorological parameters such as temperature, pressure and humidity, and thus varies with the geographic location of the site, the month of the year, the height of an FS station above sea level and the elevation angle of the slant path and the operating frequency. The procedure for calculating the slant path attenuation is the line-by-line procedure given in Annex 1 to Recommendation ITU-R P.676.

The detailed calculations of atmospheric attenuation may utilize local information of average water vapour content in the driest month and of other meteorological parameters along with the atmospheric models of Recommendation ITU-R P.835. Where this information is not available, the following results provide a simple procedure for estimating atmospheric attenuation.

The formulae given in § 2 consider each of the frequency bands which are allocated to the FS and one of the BSS, MSS or space science services on a shared basis and are presented for five representative geographical areas of the world (northern and southern hemispheres).

2 Estimation of slant path attenuation

For the purpose of this simplified estimation, an FS station is identified as being within one of three climate areas depending only on the latitude (absolute value) of the station:

– low-latitudes within 22.5° of the Equator;

– mid-latitudes greater than 22.5°, but less than 45° from the Equator;

– high-latitudes of 45° or more from the Equator.

Table 1 shows the climate parameters for each of these areas. Note that the sea-level water vapour density for the low-latitude area is lower than that prescribed in Recommendation ITU-R P.835 corresponding to the dry season. The attenuation values for these areas have been determined as a function of the elevation angle of the actual transmission path from the FS station to the position of a space station (GSO or non-GSO). The numerical formulae for atmospheric attenuation which approximate the theoretical values are given in the following sections, where:

$A_L(h, \theta)$, $A_M(h, \theta)$ and $A_H(h, \theta)$: total atmospheric absorption loss (dB) for the low-latitude, mid-latitude and high-latitude areas, respectively;

h and θ: FS antenna altitude above sea level (km) and elevation angle (degrees), respectively.

TABLE 1

Parameters at sea level for the climate areas

Climate area	Temperature (K)	Atmospheric pressure (hPa)	Water vapour density (g/m^3)
Low-latitude	300.4	1 012.0	10.0
Mid-latitude	272.7	1 018.9	3.5
High-latitude	257.4	1 010.8	1.23

The method in Annex 1 to Recommendation ITU-R P.676 was used for integration. The height profiles of temperature, pressure and water vapour density as defined in Recommendation ITU-R P.835 were used in calculating the loss. The approximation was carried out for $0 \le h \le 3$ km and $0° \le \theta \le 90°$.

The actual elevation angle may be determined from the elevation angle developed under free space propagation conditions using the method in Recommendation ITU-R F.1333. For actual elevation angles below 0°, the attenuation for 0° should be used.

NOTE 1 – In some situations, it may become necessary to estimate the attenuation at a specific frequency based on the following formulae. For example, if it is necessary to find the attenuation in the low-latitude area at 36.5 GHz, it is possible to estimate this attenuation as an interpolation of the attenuation at 36.0 GHz (see equation (9a)) and that at 37.0 GHz (see equation (10a)). However, for such interpolation to be accurate, the two adjacent representative frequencies should be reasonably close to each other. In addition, special caution is required near 22.24 GHz (water vapour resonance frequency) where the linear interpolation may not apply.

2.1 Frequency band 11.7-12.75 GHz

In this frequency band, the attenuation is larger at higher frequencies and, therefore, the following formulae give the attenuation at 11.7 GHz.

$$A_L(h, \theta) = 3.84 / [1 + 0.8598\,\theta + h\,(0.2815 + 0.3031\,\theta) + 0.1148\,h^2] \tag{1a}$$

$$A_M(h, \theta) = 3.23 / [1 + 0.7585\,\theta + h\,(0.4154 + 0.2232\,\theta)] \tag{1b}$$

$$A_H(h, \theta) = 3.12 / [1 + 0.7487\,\theta + h\,(0.3792 + 0.2102\,\theta)] \tag{1c}$$

2.2 Frequency band 18.6-18.8 GHz

In this frequency band, the attenuation is larger at higher frequencies and, therefore, the following formulae give the attenuation at 18.6 GHz.

$$A_L(h, \theta) = 15.16 / [1 + 0.9258\,\theta + 0.03625\,\theta^2 + h\,(0.2981 + 0.4352\,\theta) + h^2\,(0.2429 + 0.1330\,\theta)] \tag{2a}$$

$$A_M(h, \theta) = 7.98 / [1 + 0.9103\,\theta + h\,(0.2862 + 0.4112\,\theta) + 0.1469\,h^2] \tag{2b}$$

$$A_H(h, \theta) = 5.67 / [1 + 0.8172\,\theta + h\,(0.2017 + 0.3017\,\theta) + 0.1057\,h^2] \tag{2c}$$

2.3 Frequency band 21.2-21.4 GHz

In this frequency band, the attenuation is larger at higher frequencies and, therefore, the following formulae give the attenuation at 21.2 GHz.

$$A_L(h, \theta) = 38.08 / [1 + 0.8485\,\theta + 0.06485\,\theta^2 - 0.002121\,\theta^3 + 0.1669 \times 10^{-4}\,\theta^4 + h\,(0.2934 + 0.3816\,\theta) + h^2\,(0.09441 + 0.1701\,\theta) + 0.04082\,h^3] \tag{3a}$$

$$A_M(h, \theta) = 16.70 / [1 + 0.8126\,\theta + 0.02719\,\theta^2 + h\,(0.2395 + 0.2772\,\theta) + h^2\,(0.1180 + 0.08558\,\theta)] \tag{3b}$$

$$A_H(h, \theta) = 9.66 / [1 + 0.6721\,\theta + 0.04348\,\theta^2 + h\,(0.07322 + 0.3655\,\theta) + 0.1177\,h^2] \tag{3c}$$

2.4 Frequency band 21.4-22.0 GHz

In this frequency band, the attenuation is larger at higher frequencies and, therefore, the following formulae give the attenuation at 21.4 GHz.

$$A_L(h, \theta) = 40.39 / [1 + 0.8413\,\theta + 0.06418\,\theta^2 - 0.002095\,\theta^3 + 0.1646 \times 10^{-4}\,\theta^4 + h\,(0.2871 + 0.3732\,\theta) + h^2\,(0.09311 + 0.1638\,\theta) + 0.03859\,h^3] \tag{4a}$$

$$A_M(h, \theta) = 17.59 / [1 + 0.8066\,\theta + 0.02682\,\theta^2 + h\,(0.2354 + 0.2699\,\theta) + h^2\,(0.1135 + 0.08342\,\theta)] \tag{4b}$$

$$A_H(h, \theta) = 10.08 / [1 + 0.6205\,\theta + 0.04369\,\theta^2 + h\,(0.06793 + 0.3605\,\theta) + 0.1155\,h^2] \tag{4c}$$

2.5 Frequency band 22.21-22.5 GHz

In this frequency band, the attenuation is at its maximum at 22.24 GHz due to water vapour resonance and lowest at 22.5 GHz and, therefore, the following formulae give the attenuation at 22.5 GHz.

$$A_L(h, \theta) = 47.88 / [1 + 0.78405\,\theta + 0.10659\,\theta^2 - 0.0091566\,\theta^3 + 0.30002 \times 10^{-3}\,\theta^4 - 0.40272 \times 10^{-5}\,\theta^5 + 0.18706 \times 10^{-7}\,\theta^6 + h\,(0.29782 + 0.30275\,\theta) + h^2\,(0.066824 + 0.17983\,\theta) + 0.038747\,h^3] \tag{5a}$$

$$A_M(h, \theta) = 20.36 / [1 + 0.7223\,\theta + 0.06031\,\theta^2 - 0.001980\,\theta^3 + 0.1572 \times 10^{-4}\,\theta^4 + h\,(0.2053 + 0.2374\,\theta) + h^2\,(0.1101 + 0.08933\,\theta)] \tag{5b}$$

$$A_H(h, \theta) = 11.55 / [1 + 0.6073\,\theta + 0.04379\,\theta^2 + h\,(0.05750 + 0.3490\,\theta) + 0.1102\,h^2] \tag{5c}$$

2.6 Frequency band 23.6-24.0 GHz

In this frequency band, the attenuation is smaller at higher frequencies and, therefore, the following formulae give the attenuation at 24.0 GHz.

$$A_L(h, \theta) = 40.20 / [1 + 0.8774\,\theta + 0.06742\,\theta^2 - 0.002221\,\theta^3 + 0.1759 \times 10^{-4}\,\theta^4 + h\,(0.3193 + 0.4177\,\theta) + h^2\,(0.1014 + 0.1945\,\theta) + 0.05008\,h^3] \tag{6a}$$

$$A_M(h, \theta) = 17.88 / [1 + 0.8377\,\theta + 0.02861\,\theta^2 + h\,(0.2587 + 0.3070\,\theta) + h^2\,(0.1362 + 0.09479\,\theta)] \tag{6b}$$

$$A_H(h, \theta) = 10.51 / [1 + 0.6504\,\theta + 0.04326\,\theta^2 + h\,(0.08915 + 0.3870\,\theta) + 0.1285\,h^2] \tag{6c}$$

2.7 Frequency band 25.25-27.5 GHz

In this frequency band, the attenuation is smaller at higher frequencies and, therefore, the following formulae give the attenuation at 27.5 GHz.

$$A_L(h, \theta) = 22.73 / [1 + 0.9463\,\theta + 0.03455\,\theta^2 + h\,(0.3232 + 0.4519\,\theta) + h^2\,(0.2486 + 0.1317\,\theta)] \tag{7a}$$

$$A_M(h, \theta) = 11.96 / [1 + 0.8121\,\theta + 0.03055\,\theta^2 + h\,(0.2619 + 0.4728\,\theta) + 0.1490\,h^2] \tag{7b}$$

$$A_H(h, \theta) = 8.77 / [1 + 0.8259\,\theta + h\,(0.2163 + 0.3037\,\theta) + 0.1067\,h^2] \tag{7c}$$

2.8 Frequency band 31.8-33.0 GHz

In this frequency band, the attenuation is larger at higher frequencies and, therefore, the following formulae give the attenuation at 31.8 GHz.

$$A_L(h, \theta) = 19.55 / [1 + 0.9263\,\theta + 0.02442\,\theta^2 + h\,(0.3399 + 0.4324\,\theta) + h^2\,(0.1898 + 0.07463\,\theta)] \tag{8a}$$

$$A_M(h, \theta) = 12.04 / [1 + 0.8112\,\theta + 0.01934\,\theta^2 + h\,(0.2740 + 0.3825\,\theta) + 0.1155\,h^2] \tag{8b}$$

$$A_H(h, \theta) = 9.90 / [1 + 0.8140\,\theta + h\,(0.2401 + 0.2679\,\theta) + 0.08673\,h^2] \tag{8c}$$

2.9 Frequency band 36.0-37.0 GHz

In this frequency band, the attenuation is larger at higher frequencies and, therefore, the following formulae give attenuation at 36.0 GHz.

$$A_L(h, \theta) = 21.60 / [1 + 0.8102\,\theta + 0.05726\,\theta^2 - 0.001887\,\theta^3 + 0.1488 \times 10^{-4}\,\theta^4 + h\,(0.2731 + 0.5166\,\theta) + 0.1884\,h^2] \tag{9a}$$

$$A_M(h, \theta) = 15.00 / [1 + 0.8197\,\theta + 0.01342\,\theta^2 + h\,(0.3078 + 0.2651\,\theta) + h^2\,(0.07561 + 0.03399\,\theta)] \tag{9b}$$

$$A_H(h, \theta) = 12.80 / [1 + 0.7376\,\theta + 0.01588\,\theta^2 + h\,(0.2185 + 0.2806\,\theta) + 0.07660\,h^2] \tag{9c}$$

2.10 Frequency band 37.0-38.0 GHz

In this frequency band, the attenuation is larger at higher frequencies and, therefore, the following formulae give the attenuation at 37.0 GHz.

$$A_L(h, \theta) = 22.63 / [1 + 0.8064\,\theta + 0.05519\,\theta^2 - 0.001808\,\theta^3 + 0.1416 \times 10^{-4}\,\theta^4 + h\,(0.2740 + 0.4986\,\theta) + 0.1789\,h^2] \tag{10a}$$

$$A_M(h, \theta) = 16.03 / [1 + 0.8146\,\theta + 0.01315\,\theta^2 + h\,(0.3044 + 0.2598\,\theta) + h^2\,(0.07308 + 0.03276\,\theta)] \tag{10b}$$

$$A_H(h, \theta) = 13.85 / [1 + 0.7369\,\theta + 0.01556\,\theta^2 + h\,(0.2197 + 0.2771\,\theta) + 0.07495\,h^2] \tag{10c}$$

2.11 Frequency band 39.5-40.0 GHz

In this frequency band, the attenuation is larger at higher frequencies and, therefore, the following formulae give the attenuation at 39.5 GHz.

$$A_L(h, \theta) = 26.03 / [1 + 0.7941\,\theta + 0.05051\,\theta^2 - 0.001631\,\theta^3 + 0.1259 \times 10^{-4}\,\theta^4 + h\,(0.2739 + 0.4541\,\theta) + 0.1562\,h^2] \tag{11a}$$

$$A_M(h, \theta) = 19.39 / [1 + 0.8019\,\theta + 0.01254\,\theta^2 + h\,(0.2957 + 0.2470\,\theta) + h^2\,(0.06718 + 0.03002\,\theta)] \tag{11b}$$

$$A_H(h, \theta) = 17.46 / [1 + 0.7615\,\theta + 0.01187\,\theta^2 + h\,(0.2619 + 0.2041\,\theta) + h^2\,(0.05213 + 0.02735\,\theta)] \tag{11c}$$

2.12 Frequency band 40.0-40.5 GHz

In this frequency band, the attenuation is larger at higher frequencies and, therefore, the following formulae give the attenuation at 40.0 GHz.

$$A_L(h, \theta) = 26.87 / [1 + 0.7912\,\theta + 0.04963\,\theta^2 - 0.001599\,\theta^3 + 0.1230 \times 10^{-4}\,\theta^4 + h\,(0.2735 + 0.4451\,\theta) + 0.1517\,h^2] \tag{12a}$$

$$A_M(h, \theta) = 20.23 / [1 + 0.7993\,\theta + 0.01243\,\theta^2 + h\,(0.2939 + 0.2444\,\theta) + h^2\,(0.06605 + 0.02951\,\theta)] \tag{12b}$$

$$A_H(h, \theta) = 18.33 / [1 + 0.7608\,\theta + 0.01179\,\theta^2 + h\,(0.2620 + 0.2033\,\theta) + h^2\,(0.05148 + 0.02706\,\theta)] \tag{12c}$$

2.13 Frequency band 40.5-42.5 GHz

In this frequency band, the attenuation is larger at higher frequencies and, therefore, the following formulae give the attenuation at 40.5 GHz.

$$A_L(h, \theta) = 27.78 / [1 + 0.7880\,\theta + 0.04877\,\theta^2 - 0.001566\,\theta^3 + 0.1202 \times 10^{-4}\,\theta^4 + h\,(0.2729 + 0.4361\,\theta) + 0.1473\,h^2] \tag{13a}$$

$$A_M(h, \theta) = 20.76 / [1 + 0.6980\,\theta + 0.04731\,\theta^2 - 0.001508\,\theta^3 + 0.1157 \times 10^{-4}\,\theta^4 + h\,(0.2497 + 0.3257\,\theta) + 0.07995\,h^2] \tag{13b}$$

$$A_H(h, \theta) = 18.92 / [1 + 0.6577\,\theta + 0.04678\,\theta^2 - 0.001484\,\theta^3 + 0.1139 \times 10^{-4}\,\theta^4 + h\,(0.2200 + 0.2811\,\theta) + 0.06507\,h^2] \tag{13c}$$

2.14 Frequency band 55.78-59.0 GHz

In this frequency band, the zenith oxygen absorption attenuation from the ground at sea level exceeds 50 dB (see Recommendation ITU-R P.676). Therefore, it is not necessary to consider any constraints for frequency sharing between the FS and space science services.

2.15 Frequency band 64.0-66.0 GHz

In this frequency band, the attenuation is smaller at higher frequencies and, therefore, the following formulae give the attenuation at 66.0 GHz.

$$\begin{aligned} A_L(h, \theta) = 528.4 / [1 &+ 0.568865\,\theta + 0.0640672\,\theta^2 - 0.00696532\,\theta^3 \\ &+ 0.385420 \times 10^{-3}\,\theta^4 - 0.114133 \times 10^{-4}\,\theta^5 + 0.181220 \times 10^{-6}\,\theta^6 \\ &- 0.145280 \times 10^{-8}\,\theta^7 + 0.461010 \times 10^{-11}\,\theta^8 \\ &+ h\,(0.178140 + 0.117782\,\theta + 0.00785552\,\theta^2 - 0.228606 \times 10^{-3}\,\theta^3 \\ &+ 0.159694 \times 10^{-5}\,\theta^4) + h^2\,(0.0367537 + 0.0186594\,\theta)] \end{aligned} \tag{14a}$$

$$\begin{aligned} A_M(h, \theta) = 522.9 / [1 &+ 0.596648\,\theta + 0.0698675\,\theta^2 - 0.00806908\,\theta^3 \\ &+ 0.466138 \times 10^{-3}\,\theta^4 - 0.141814 \times 10^{-4}\,\theta^5 + 0.229255 \times 10^{-6}\,\theta^6 \\ &- 0.186157 \times 10^{-8}\,\theta^7 + 0.596475 \times 10^{-11}\,\theta^8 \\ &+ h\,(0.205676 + 0.125103\,\theta + 0.0107935\,\theta^2 - 0.326445 \times 10^{-3}\,\theta^3 \\ &+ 0.235065 \times 10^{-5}\,\theta^4) + h^2\,(0.0399720 + 0.0251223\,\theta)] \end{aligned} \tag{14b}$$

$$\begin{aligned} A_H(h, \theta) = 531.9 / [1 &+ 0.616560\,\theta + 0.0701934\,\theta^2 - 0.00821842\,\theta^3 \\ &+ 0.476119 \times 10^{-3}\,\theta^4 - 0.143928 \times 10^{-4}\,\theta^5 + 0.230683 \times 10^{-6}\,\theta^6 \\ &- 0.185825 \times 10^{-8}\,\theta^7 + 0.591348 \times 10^{-11}\,\theta^8 \\ &+ h\,(0.224143 + 0.119089\,\theta + 0.0133543\,\theta^2 - 0.416213 \times 10^{-3}\,\theta^3 \\ &+ 0.308010 \times 10^{-5}\,\theta^4) + h^2\,(0.0388456 + 0.0290534\,\theta)] \end{aligned} \tag{14c}$$