RECOMMENDATION ITU-R F.1820

Power flux-density at international borders for high altitude platform stations providing fixed wireless access services to protect the fixed service in neighbouring countries in the 47.2-47.5 GHz and 47.9-48.2 GHz bands

(Question ITU-R 212/9)

(2007)

Scope

This Recommendation provides power flux density (pfd) values for the purpose of protecting conventional fixed service stations in neighbouring administrations from co-channel interference from a high altitude platform station (HAPS) operating in the frequency bands 47.2-47.5 GHz and 47.9-48.2 GHz.

Acronyms

UAC Urban area coverage

SAC Suburban area coverage

RAC Rural area coverage

The ITU Radiocommunication Assembly,

considering

a) that new technology utilizing high altitude platform stations (HAPS) in the stratosphere is being developed;

b) that WRC-97 designated the 47.2-47.5 GHz and 47.9-48.2 GHz bands for use as a co-primary fixed service for HAPS deployment;

c) that Recommendation ITU-R F.1500 contains the characteristics of systems in the fixed service planned for HAPS usage in the 47.2-47.5 GHz and 48.2-48.5 GHz bands;

d) that, while the decision to deploy HAPS can be taken on a national basis, such deployment may affect neighbouring administrations, particularly in small countries,

recommends

1 that for the purpose of protecting conventional fixed service stations in neighbouring administrations from co-channel interference, based on the methodology described in Annex 1, a HAPS operating in the frequency bands 47.2-47.5 GHz and 47.9-48.2 GHz should not exceed the following power flux-density (pfd) values at the Earth's surface outside an administration's borders, unless explicit agreement of the affected administration is provided at the time of the notification of HAPS:

$$-141 \quad \text{dB(W/(m}^2 \cdot \text{MHz))} \quad \text{for} \quad 0° \le \theta \le 3°$$

$$-141 + 2.0(\theta - 3) \quad \text{dB(W/(m}^2 \cdot \text{MHz))} \quad \text{for} \quad 3° < \theta \le 13°$$

$$-121 \quad \text{dB(W/(m}^2 \cdot \text{MHz))} \quad \text{for} \quad 13° < \theta \le 90°$$

where θ is the angle of the arrival above the horizontal plane of the Earth.

Annex 1

Methodology to determine pfd values at international borders for HAPS providing fixed wireless access services to protect the fixed service in neighbouring countries in the 47.2-47.5 GHz and 47.9-48.2 GHz bands

1 Introduction

This Annex describes a methodology for establishing pfd values at international borders for HAPS providing FWA services to protect conventional fixed service stations in neighbouring countries in the 47.2-47.5 GHz and 47.9-48.2 GHz bands, and the pfd limits at international borders for HAPS, based on the characteristics for HAPS in Recommendation ITU-R F.1500.

2 System characteristics

2.1 The high altitude platform system

The parameters used in this analysis are given in Recommendation ITU-R F.1500 and are as follows:

TABLE 1

HAPS coverage zones

Coverage area	Elevation angles (degrees)	Ground range (platform at 21 km) (km)
UAC	90-30	0-36
SAC	30-15	36-76.5
RAC	15-5	76.5-203

TABLE 2

Platform station transmitter parameters

Communication to	Transmitter power (dBW)	Antenna gain (dBi)(1)
UAC	1.3	30
SAC	1.3	30
RAC	3.5	38
Gateway (UAC)	0	35
Gateway (SAC)	9.7	38

(1) Maximum antenna gains.

2.2 Antenna radiation patterns

The antenna radiation patterns for platform antennas conform to Recommendation ITU-R S.672.

2.3 Atmospheric attenuation

The atmospheric attenuation formulas are obtained from Recommendation ITU-R F.1501. For the interference analysis, only the minimum attenuation formula is of interest, hence the formula for the high-latitude regions at 47.2 GHz is selected to provide a worst-case analysis.

$$A_H(h,\theta) = 46.70/[1 + 0.68720\theta + 0.03637\theta^2 - 0.001105\theta^3 + 0.8087\times10^{-5}\theta^4 + h(0.2472 + 0.18190\theta) + h^2(0.04858 + 0.032210\theta)] \quad (1)$$

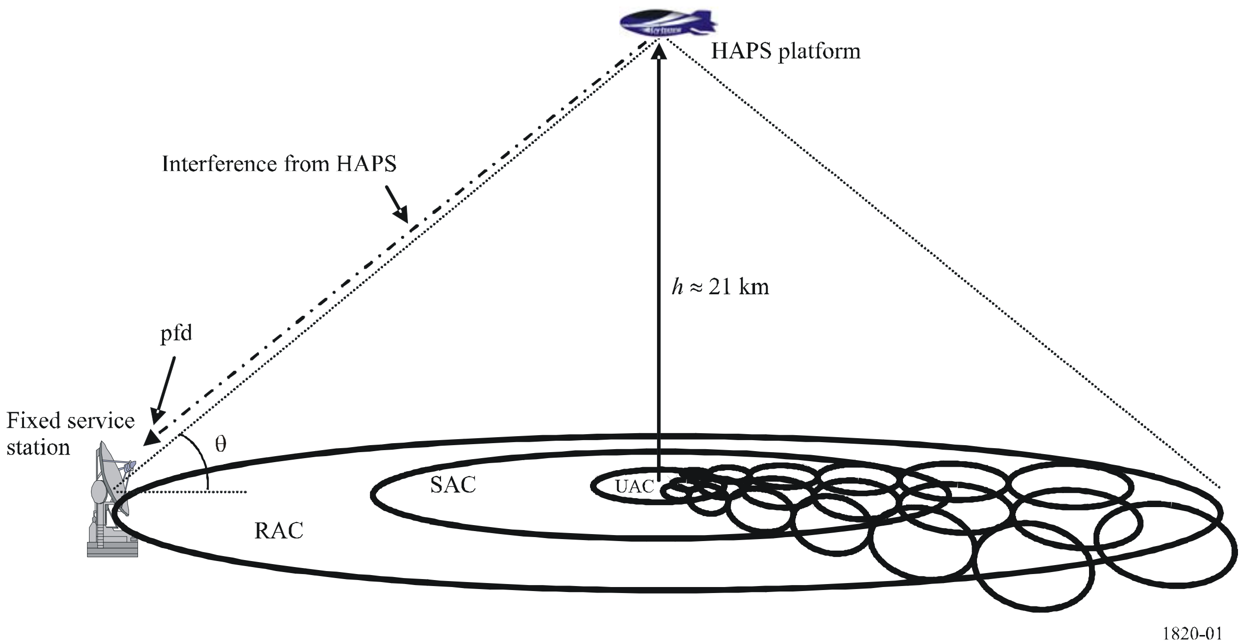
The formula is valid for $0 \le h \le 3$ km and $0 \le \theta \le 90°$, where θ (degrees) is the elevation angle of the ground station with respect to the HAPS platform, and h (km) is the altitude of the ground station above sea level. For actual elevation angles below 0°, the attenuation for 0° should be used.

2.4 Interference scenario

The interference scenario is assumed as shown in Fig. 1. In this scenario, the fixed service station of an adjacent administration that receives the interference signal emitted by HAPS is located either at or beyond the edge of the HAPS coverage. The aggregated interference signal from HAPS from all the transmitters on board the HAPS is computed to provide a pfd bound.

FIGURE 1

Interference scenario



UAC, SAC and RAC describe respectively the urban, suburban and rural area coverage by HAPS.

The expected received pfd at the ground station receiver can be calculated by equation (2) as used in Recommendation ITU-R SF.1481-1:

$$fdr = P + Gt - Ltf - La - Lp - 10\log B - 10\log(4\pi d^2) - 60 \text{ dB(W/(m}^2\cdot\text{MHz))} \quad (2)$$

where:

- *fdr*: expected received carrier pfd (dB(W/(m^2 · MHz)))
- *P*: transmitting output power (dBW)
- *B*: transmitting output bandwidth (dBMHz)
- *Gt*: transmitting antenna gain (dBi)
- *Ltf*: antenna feeder loss (dB)
- *Gr*: gain of the receiving antenna (dBi)
- *La*: atmospheric absorption for a particular elevation angle (dB)
- *Lp*: attenuation due to other propagation effects (dB)
- λ: wavelength (m)
- *d*: distance between HAPS and the ground receiver (km).

The allowable pfd level for the fixed service station can be inferred from the typical characteristics of a fixed service station, as shown in Table 3 (Table 27, Recommendation ITU-R F.758-4):

TABLE 3

FS receiver parameters

Maximum antenna gain (dBi)	46
Antenna diameter (m)	0.9
Receiver noise figure (dB)	5
Modulation	256 QAM
Frequency band (GHz)	47.2-50.2
Receiver IF bandwidth (MHz)	50
Nominal long-term interference (dBW)	−132
Inferred interference criterion (dB(W/MHz))	−149

The interference criterion in Table 3 principally reflects the receiver thermal noise minus 10 dB criterion which ensures that the penalty in the received signal-to-noise ratio is no more than 0.4 dB. For the purpose of estimating the pfd limit, the effective aperture of an ideal antenna having the same antenna gain should be calculated. Using the formula for an ideal antenna:

$$D_{effective} = \frac{\lambda}{\pi} \cdot 10^{0.05 \cdot G_{FS}} \tag{3}$$

where D is the diameter of the effective aperture of the ideal antenna, G_{FS} is the actual maximum antenna gain, and λ is the wavelength of the transmitted RF. The pfd limit for bore-sight interference from a HAPS platform can be determined as:

$$\begin{aligned} PFD_{limit} &= (Interference\_criterion) - 10 \log\left(\frac{\pi \cdot D_{effective}^2}{4}\right) \\ &= (Interference\_criterion) - G_{FS} - 10 \log\left(\frac{\lambda^2}{4\pi}\right) \\ &= -140.02 \text{ dB(W/(m}^2 \cdot \text{MHz))} \end{aligned} \tag{4}$$

To compute the aggregated interference level from a HAPS platform, the array factor must be calculated first in order to obtain the effective transmitting antenna gain Gt in equation (5).

The array factor is computed assuming the HAPS antennas are arranged as a hexagonal lattice on a hemispherical surface, bearing in mind the fact the antenna array would not cover the entire hemisphere even with a minimum elevation angle of zero, so this computation corresponds to the upper bound of the pfd limit. A further simplifying assumption is to replace all other RAC antennas by lower gain SAC antennas except the one that is pointing directly toward the interfered ground receiver. This assumption increases the adjacent co-channel beam coupling since the lower gain antenna has higher side lobes. A $7\times$ frequency reuse plan is used in accordance with Recommendation ITU-R F.1500.

Figures 2 and 3 show an example of the HAPS platform array factor calculation with the parameters based on Table 3 except that the UAC and SAC antenna gains are allowed to vary from 10 dB below to no change of the values listed in Table 3.

The total number of antennas clearly depends on the beamwidth of the individual antenna; the larger the beamwidth, the smaller the number. This is demonstrated in Fig. 2. The number of antennas in the array is determined in the computation by the beamwidth of the individual antenna since the beams are separated from one another by the −3 dB beamwidth to obtain optimal uniform coverage. Hence the lower the single antenna gain, the smaller the number of antennas.

If all antennas in the array have the same gain, then approximately:

$$Number\_of\_antennas \approx \frac{1-\sin(\theta_{elevation})}{1-\cos\left(\frac{\theta_{beamwidth}}{2}\right)}$$

Where the $\theta_{elevation}$ is the minimum elevation angle of the array, and the $\theta_{beamwidth}$ is the −3 dBi beamwidth of the individual antenna. It can be seen that the higher the individual antenna gain, the smaller the half beamwidth, and hence the larger the number of antennas are needed in order to provide −3 dB coverage. If fewer antennas are used, then the adjacent beams will intercept below the −3 dBi level, with the consequent poorer edge coverage. The numbers in Fig. 2 are from actual simulation, hence are slightly different from the above formula.

The array factor in Fig. 3 is calculated by adding up all the contributions from the side-lobe emission of other antennas in addition to the boresight contribution from the antenna that points at the fixed service ground station and then dividing it by the gain of the boresight antenna. Using the array factor, the pfd can be calculated from the single antenna equation (5) by replacing the single antenna gain by the antenna gain multiplied by the array factor.

Since the computed array factor is about 1.1, it means that the effective single antenna gain should be approximately 11 000, or 40.4 dBi.

More specifically:

$$Array\_factor = \frac{\sum_n G_n(\psi_n)}{G_0(0)} \tag{5}$$

where $G_0(0)$ corresponds to the boresight gain of the HAPS antenna that pointed directly at the fixed service station, and remaining n ranges over all other co-channel antennas. The antenna gains for the co-channel antennas are side-lobe gains at the appropriate angles.

FIGURE 2

Number of antennas vs. single antenna gain

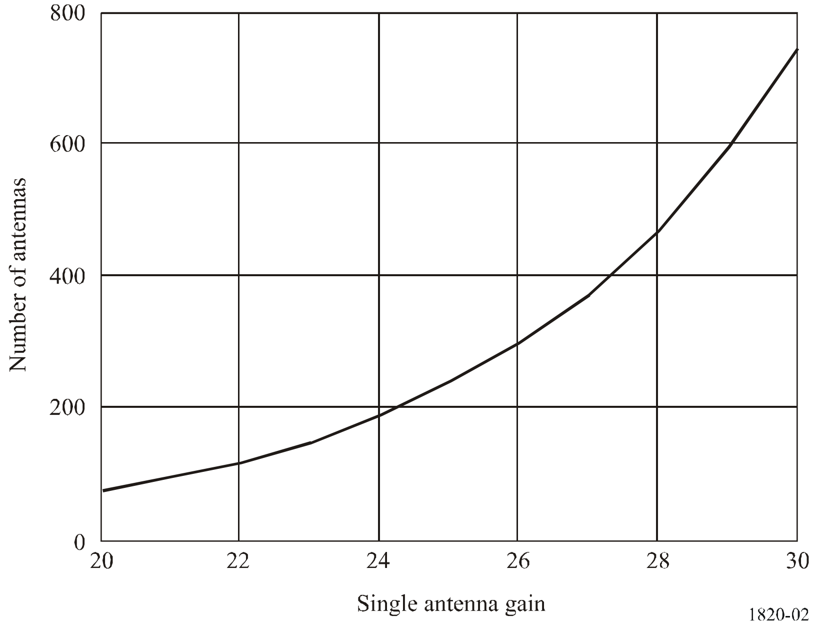


FIGURE 3

Array factor vs. single antenna gain

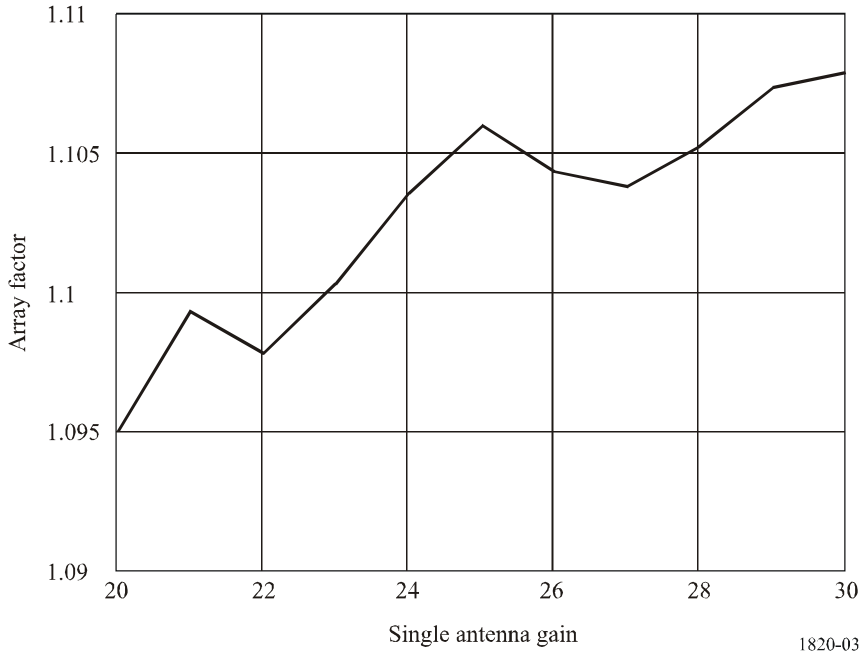


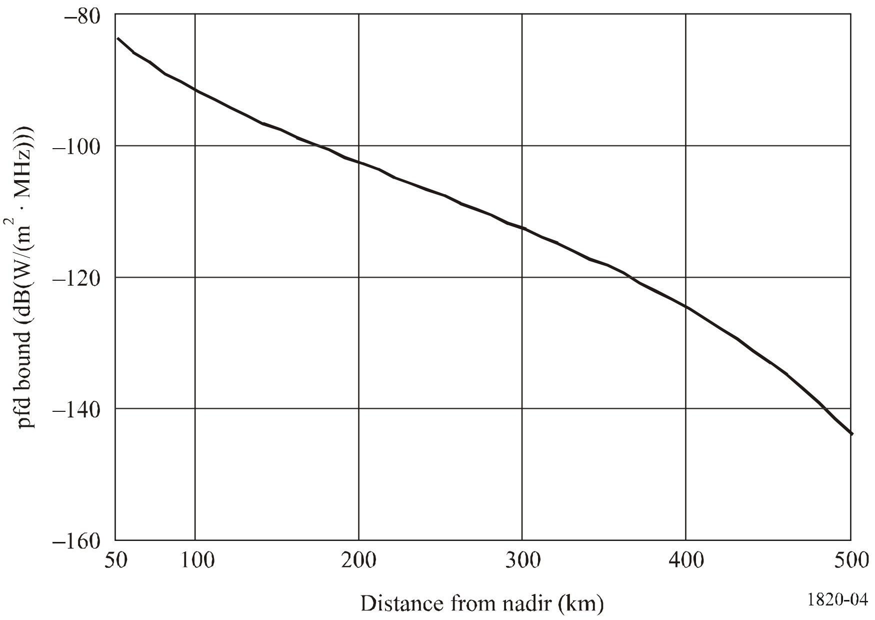
Figure 2 reflects the fact that as the gain of the UAC/SAC antennas increases, their beamwidths also decrease, hence the total number of beams also increases correspondingly, with concomitant growth in platform network capacity.

In Fig. 3, the computed array factors are all clustered around 1.1, irrespective of the single antenna gain. This is reasonable since the 7:1 frequency reuse arrangement of the antenna array minimizes the co-channel interference from adjacent co-channel antennas. The array factor increases the transmitting antenna gain by 0.4 dB in equation (5).

The computed pfd bound is shown in Fig. 4. The pfd bound is derived mainly from equation (5) by replacing the single antenna gain *Gt* with an effective single antenna gain as described in 1. The distance between HAPS antennas and the fixed service ground station is determined from the distance from nadir by the appropriate spherical geometry.

FIGURE 4

pfd bound vs. distance from nadir of HAPS platform



In the above calculation, a transmitting bandwidth of 11 MHz and a combined cable/feeder loss of 5 dB are assumed. The computed pfd is in the range of −84 dB(W/(m^2 · MHz)) and −144.2 dB(W/(m^2 · MHz)) for distances from 50 km to 500 km from nadir, the larger figure corresponding to a distance of 50 km from nadir. The pfd bound dips below the fixed service pfd interference limit when the outmost boundary of HAPS RAC coverage is greater than 470 km. The pfd decreases sharply when the distance becomes greater than 200 km, signifying a rapid increase in atmospheric attenuation. The elevation angle that corresponds to the distance of 200 km from nadir is about 5°. The above computation is based on the assumption that the interfered fixed service ground station is at sea level. Fixed service ground stations at higher than sea level will receive higher interference levels because of the reduced atmospheric attenuation.

HAPS link budget for RAC includes a 20 dB rain fade margin; hence it would be possible to use automatic downlink power control by reducing the transmitting power by 20 dB during clear-sky conditions to reduce boresight interference to the fixed service station, assuming the fixed service station is pointing at HAPS platform. By shutting down the RAC beam that points directly at the fixed service station, another 10 dB reduction in boresight interference level can be achieved. This would still require the distance from the fixed service station to nadir of HAPS platform to be greater than 260 km. The fixed service station can also mitigate the interference from HAPS by pointing away from HAPS platform. Given the extremely small beamwidth of the fixed service station antenna (> 1°), this is possible, although HAPS platform's station keeping is considerably looser than that of the GSO satellite if the fixed service antenna is pointed too closely to the nominal position of HAPS. However, a fixed service antenna typically is aimed horizontally toward another distant fixed service antenna, whereas HAPS platform antenna's minimum elevation angle is about 4°, hence the difference in the elevation angles between the interfering HAPS antennas and the fixed service antenna alone can provide at least a 25 dB reduction of the interference signal.

Environmental screening of the fixed service antenna also helps to further reduce off-boresight interference.

The solid curve in Fig. 5 depicts the computed pfd bound as a function of the elevation angle of the HAPS platform as viewed from the fixed service station. The dashed curve shows the same bound after the 20 dB rain attenuation margin has been subtracted. Note that the computed pfd bound (20 dB) is fairly flat for elevation angles above 13°, and drops off abruptly for elevation angles below 3°.

FIGURE 5

pfd bound vs. elevation angle

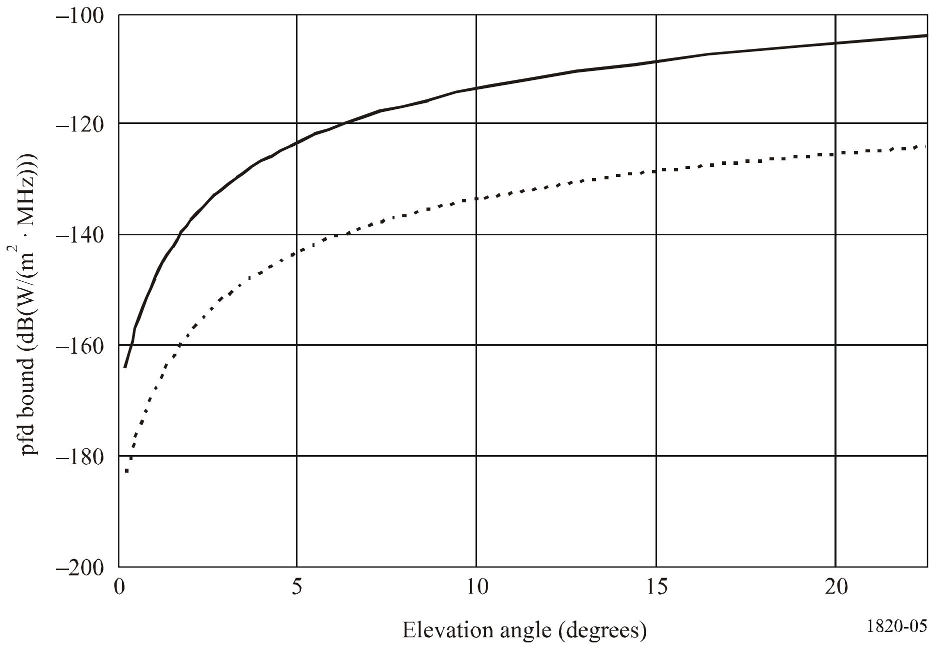


FIGURE 6

Atmosphere attenuation vs. elevation angle

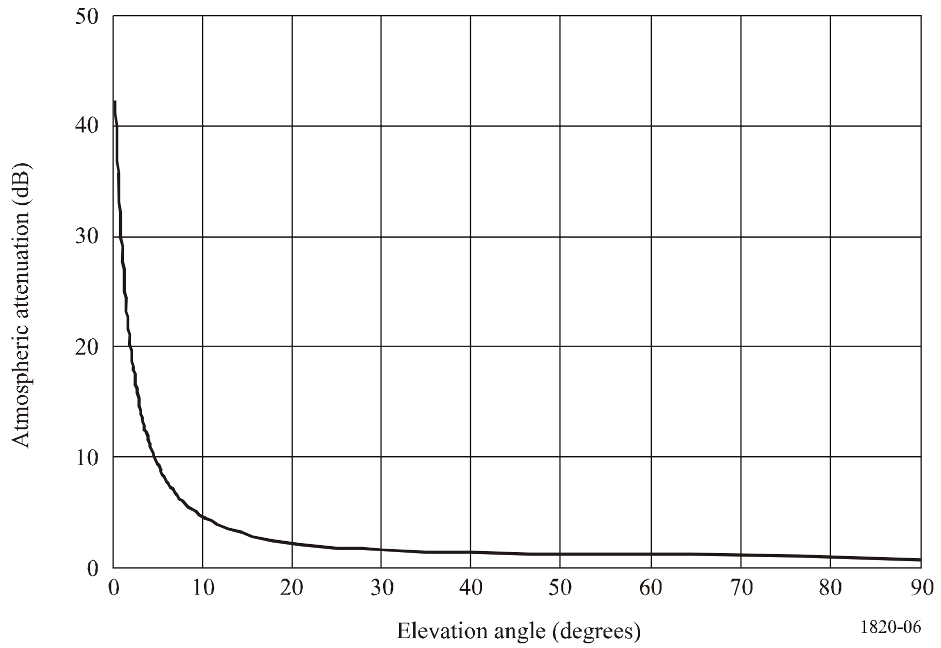


Figure 6 depicts the variation of the minimum propagation attenuation due to atmospheric gases in the 47.2-48.2 GHz band as a function of the elevation angle of the HAPS platform viewed from the fixed service station, in accordance with Recommendation ITU-R F.1501. It indicates that the atmospheric attenuation remains small (0.57 dB at 90° and 1.9 dB at 22.5° or ~ 50 km from nadir), until the elevation angle drops below 13° (attenuation = 3.4 dB, distance ~ 90 km from nadir), at which point the attenuation increases almost exponentially, reaching a value of 42.2 dB at 0.154° (approximately 500 km from nadir). At 3° (~ 280 km from nadir) the atmosphere attenuation is 13.9 dB. Notice that the atmospheric attenuation decreases rapidly with altitude of the ground station. Above 10 km in altitude, the atmospheric attenuation varies from 0.47 dB to 1.22 dB between 76 km and 200 km (from nadir).

3 Proposed HAPS pfd limit at international borders to protect fixed service

Based on the results of this study it is proposed that for the purpose of protecting fixed service ground stations in neighbouring administrations from co-channel interference, a HAPS operating in the frequency bands 47.2-47.5 GHz and 47.9-48.2 GHz should not exceed the following co-channel pfd at the Earth's surface outside an administration's borders, unless explicit agreement of the affected administration is provided at the time of the notification of HAPS;

– -141 dB(W/(m^2 · MHz)) for $0° \leq \theta \leq 3°$

– $-141 + 2.0(\theta - 3)$ dB(W/(m^2 · MHz)) for $3° < \theta \leq 13°$

– -121 dB(W/(m^2 · MHz)) for $13° < \theta \leq 90°$

where θ is the angle of the arrival above the horizontal plane of the Earth.

The rationale for selection of an angle of arrival range smaller than 3° is that there is a greater likelihood that the fixed service antenna may receive boresight or near-boresight interference from a HAPS platform, hence full protection is required. For angles of arrival 13° or above, boresight interference is highly unlikely, hence a 20 dB reduction of the fixed service antenna gain is assumed to reduce the pfd protection requirement from HAPS.