Electronic Communications Committee (ECC)
within
the European Conference of Postal and Telecommunications Administrations (CEPT)

ECC REPORT 156

CONDITIONS FOR POSSIBLE CO-EXISTENCE BETWEEN HAPS GATEWAY LINKS AND OTHER SERVICES/SYSTEMS IN THE 5850-7075 MHz BAND

Cardiff, January 2011

0 EXECUTIVE SUMMARY

In response to Resolution **734 (Rev.WRC-07)** calling for sharing studies for spectrum identification of HAPS (High Altitude Platform Station) gateway links in the range from 5850 to 7075 MHz, the CEPT conducted compatibility studies between HAPS system and different other services.

Services which have been considered are the following:

1) Fixed Service

2) Fixed Satellite Service (geostationary (Plan Appendix 30B RR and non-Plan) and non-geostationary)

3) Mobile Service (Intelligent Transport Systems)

4) Earth Exploration-Satellite Service

5) Radio Astronomy Service.

The following table shows the conditions under which sharing would be feasible:

Services and applications	HAPS as interferer system vs other Services
FS	**Aeronautical platform (downlink):** In order to meet the FWS nominal long term interference criterion of -147.5 dBW/10 MHz taking into account apportionment considerations of the allowable interference into the FS , the maximum e.i.r.p. at HAPS airborne antenna output should be: • for $0° \le \theta \le 20°$, θ is the off-axis angle from the nadir e.i.r.p. mask should be comply with a range between -0.5 dBW/10 MHz and 0 dBW/10 MHz; • for $20° < \theta \le 43°$, θ is the off-axis angle from the nadir e.i.r.p. mask should be comply with a range between 0 dBW/10 MHz and 2.1 dBW/10 MHz; • for $43° < \theta \le 60°$, θ is the off-axis angle from the nadir e.i.r.p. mask should be comply with a range between 2.1 dBW/10 MHz and 0.5 dBW/10 MHz. This mask relates to the e.i.r.p. that would be obtained assuming free-space loss. In order to meet the FWS nominal long term interference criterion of −147.5 dBW/10 MHz, an e.i.r.p. limit of −0.5 dBW/10 MHz for HAPS (downlink) is proposed which is invariant to an off-axis angle up to 60° from the nadir, which corresponds to a minimum elevation angle for the gateway station of 30°. **Gateway link (uplink) :** Compatibility is achieved if minimum separation distances are defined between gateway station and FWS systems. • in clear sky conditions the minimum separation distance is 730 m whereas; • in rainy conditions this minimum distance increases to 1850 m. It is assumed that a minimum elevation angle for the HAPS gateway station is limited by 30°.
FSS	To protect the geostationary non-Plan FSS networks the maximum e.i.r.p. at HAPS (airborne or ground) depends on the number of the HAPS within service area of the FSS satellite. Specific values are submitted in separate Table 2 below. The identification of HAPS "uplink" channels is not recommended in the frequency band 6725-7025 MHz where there is FSS Plan allotments Appendix 30B RR. However HAPS downlink may be considered in the frequency band 6725-7025 MHz because there is low probability of interference from HAPS downlink into FSS Plan Appendix 30B allotments even for aggregate interference case. At the same time it should be noted that *Existing systems* of Appendix 30B RR, operating in the frequency band 6725-7025 MHz in accordance with Resolution **148 (Rev.WRC-07)**, and *Additional systems* are

	out of this study. Therefore the study results may not be applicable for these systems that are also a subject of the provisions of the FSS Plan Appendix 30B RR. There is low probability of interference from single HAPS uplink or downlink into non-GSO FSS space station receiver for MOLNIA-type systems. The quite big value of margin, when single entry case of HAPS uplink or downlink impact to non-GSO FSS space station receiver for MOLNIA-type systems is considered, gives opportunity to suppose, that there will not be interference from HAPS gateway links to non-GSO FSS space station receiver of MOLNIA-type systems when aggregate case is considered.
MS	**Aeronautical platform (downlink) :** In order to meet the ITS nominal long term interference criterion of -106 dBm/MHz, the maximum e.i.r.p. at HAPS airborne antenna output should be : • e.i.r.p. = 12.6 dBm/MHz (or -7.4 dBW/10 MHz) for $0° \leq \theta \leq 22°$; • e.i.r.p. linearly increases from 12.6 dBm/MHz (or -7.4 dBW/10 MHz) to 16.2 dBm/MHz (or -3.8 dBW/10 MHz) for $22° < \theta \leq 60°$. θ is the off-axis angle from the nadir. This mask relates to the e.i.r.p. that would be obtained assuming free-space loss. It is assumed that the maximum angle of the HAPS airborne antenna deviation from the nadir should be limited to 60 degrees corresponding to the UAC of the HAPS. **Gateway link (uplink) :** Compatibility is achieved if minimum separation distances are defined between gateway station and ITS systems. • in clear sky conditions the minimum separation distance is 320 m; • in rainy conditions this minimum distance is equal to 800 m. It is assumed that a minimum elevation angle for the HAPS gateway station is limited by 30°.
EESS	Sharing between HAPS (uplink) with EESS (passive) is unlikely to be feasible in the frequency band 6425-7075 MHz due to exceed of Recommendation ITU-R RS.1029 protection criteria. Sharing between HAPS (downlink) with EESS (passive) is feasible without any specific operational limitations for HAPS. However, the impact from HAPS (downlink) emissions reflected from the ocean surface to passive sensors in the EESS has not been assessed in this Report.
RAS	In the frequency band 6650-6675.2 MHz: - sharing between HAPS (uplink) with RAS is feasible however in order to protect RAS from HAPS (uplink) it requires separation distance around 31.6 km for a single ground station on flat terrain; - sharing between HAPS (downlink) with RAS is not feasible in collocated geographical areas.

Table 1: Summary of sharing conditions where HAPS interferers with other Services and applications

	Global beam	**Hemispheric beam**	**Semi-hemispheric beam**	**Regional beam**
Maximum single-entry e.i.r.p. levels (dBW/4 kHz) (see Note)	$-1.2 - 10\log(N_{HAPS})$	$-5.2 - 10\log(N_{HAPS})$	$-10.2 - 10\log(N_{HAPS})$	$-15.2 - 10\log(N_{HAPS})$

Table 2: Maximum e.i.r.p. at the HAPS as a function of number of the HAPS to protect geostationary non-Plan FSS networks

Note : N_{HAPS} is the number of HAPS system in visibility of the geostationary satellite multiplied by the number of simultaneously transmitting stations (either on the ground or on the platforms) per system.

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LIST OF ABBREVIATIONS

Abbreviation	Explanation
APC	Automatic Power Control
CEPT	European Conference of Postal and Telecommunications Administrations
CPE	Customer Premise Equipment
DSRC	Dedicated Short Range Communications
e.i.r.p.	effective isotropically radiated power
epfd	equivalent power flux-density
EVN	European VLBI Network
FS	Fixed Service
FWS	Fixed Wireless System
GL	Gateway Link
FSL	Free Space Loss
FSS	Fixed Satellite Service
HAPS	High Altitude Platform Stations
HTA	Heavier-Than-Air platform
ITS	Intelligent Transport Systems
LTA	Lighter-Than-Air platform
MERLIN	Multi-Element Radio Linked Interferometer Network
OBU	On Board Unit
RAC	Rural Area Coverage
RSU	Road Side Unit
QAM	Quadrature Amplitude Modulation
SAC	Suburban Area Coverage
TPC	Transmitter Power Control
UAC	Urban Area Coverage
VLBI	Very Long Baseline Interferometry
WRC-12	World Radiocommunication Conference of 2012

Conditions for possible co-existence between HAPS gateway links and other services/systems in the 5850-7075 MHz band

1 INTRODUCTION

This report contains sharing studies of High Altitude Platform Stations (HAPS) with other services in the range 5 850 - 7 075 MHz. This work is a response to the Resolution **734 (WRC-07)** [missing reference].

The services that have been considered are the Fixed Service, Fixed Satellite Service (geostationary and non-geostationary), Mobile Service (more specifically the Intelligent Transport Systems (ITS)), Earth Exploration-Satellite Service (passive) and finally Radio Astronomy Service.

Appropriate interference modeling between HAPS gateway stations and stations of all those services were conducted (it is assessed interference from HAPS gateway stations into stations of existing services only).

However possible interference from HAPS gateway stations into FSS (space-to-Earth) in the band 6 700-7 075 MHz which is limited to feeder links for non-geostationary satellite systems of the mobile-satellite service (No. **5.458B RR**) was not evaluated.

2 INFORMATION ON HAPS GATEWAY SYSTEMS IN THE 5 850-7 075 MHz BAND

2.1 Introduction

A HAPS obtains its movement stability, relative to the Earth, by controlled flight in the low density, steady flowing, low velocity and non-turbulent air stream that exist at particular stratospheric altitudes. A HAPS operates at a nominally fixed location in the stratosphere at a height of 20 to 25 km. The same levels of stability, altitude and position maintenance can be achieved by the heavier-than-air (HTA) and lighter-than-air (LTA) platforms.

Typically a HAPS will maintain its position to well within 0.5 km, will have less than 1/2 degrees per hour change in heading, will have changes of altitude less than 45 m/hour and will have virtually no axial rotation. In addition, the application of electronically steerable beam-forming antennas on the HAPS and at its ground stations will further add to the directivity, selectivity and effectiveness of the gateway links and easily neutralize any minimal platform movement.

2.2 HAPS network architecture

A HAPS has the capability of carrying a large variety of wireless communication payloads that can deliver high capacity broadband services to end users. The high-level HAPS telecommunication network architecture is shown in Figure 1. There are two types of links between the payload and the ground equipment: gateway links and user links.

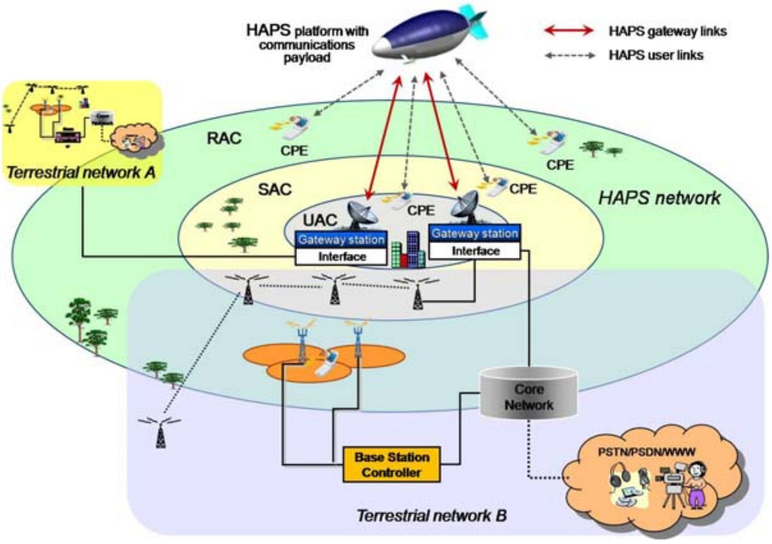

Figure 1: HAPS network configuration including gateway links and user links

For the user links, the communication is between the platform and user terminals on the ground in a cellular arrangement permitting substantial frequency. However it is emphasized that the user service links utilize frequency spectrum outside of the 5 850-7 075 MHz band and therefore user links do not consider within this study.

A HAPS gateway link is defined as a radio link between relatively fixed HAPS platform and a HAPS gateway station on the ground, located in the urban area coverage (UAC)[1], which provide interconnection with other telecommunication networks (see Table 3). A HAPS gateway link can contain unidirectional information flows such as aggregated end-user traffic for voice, data and video communications. Telemetry, tracking, command and control information related to the operation of the HAPS vehicle itself can also be contained in the HAPS gateway link. A gateway link utilizes frequency channels and subchannels that can be used in both up and down link directions using any polarization, modulation, duplexing and coding methods.

Coverage area	Elevation angles (degrees)	Ground range radius from HAPS location (km)	
		Platform at 21	Platform at 25
UAC	90-30	0-36	0-43
SAC	30-15	36-76.5	43-90.5
RAC	15-5	76.5-203	90.5-234

Table 3: Urban (UAC), suburban (SAC) and rural (RAC) area coverages

It is expected that HAPS gateway links will operate in the 5850-7075 MHz band and user service links will utilize frequency spectrum outside of the band thus this document describes only the technical and operational characteristics of the HAPS gateway links which are proposed to operate in the 5850-7075 MHz band.

A single HAPS platform will use a maximum of five gateway station links to support the maximum projected traffic load for that entire single platform. The number of gateway links (GL) deployed for each HAPS depends on the amount of end user application traffic the HAPS-based network or system must support on a backhaul basis. As the actual traffic increases, more same-frequency GLs can be deployed (up to a maximum of five). A maximum ground configuration of five same-frequency gateway links that reuse the 2 × 80 MHz frequency spectrum has been identified for HAPS use and this configuration should be used in sharing studies.

2.3 Spectrum identification and channelization

The gateway links will provide the backhaul connectivity capacity to support the type service and application being offered to end users and the associated aggregated end user traffic load tunneled through the unidirectional gateway links.

The spectrum identification for the HAPS gateway links is two 80 MHz channels in the 5850-7075 MHz band[2] for a total of 160 MHz. The sub-channelization plan can be used to divide each 80 MHz channel into six equally spaced 11 MHz subchannels separated by 2 MHz guardbands (See Figure 2). Other sub-channelization frequency plans could possibly[3] be utilized but the channelization plan shown in Fig. 2 should be utilized in the sharing studies. All sub–channels, within each 80 MHz bandwidth, are always utilized to accommodate radio links in the same direction. Only FDD/FDM will be used.

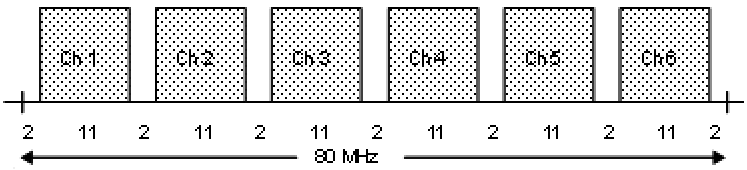

Figure 2: HAPS channelization plan

The location of the spectrum for HAPS gateway links within the 5850-7075 MHz band will largely be dependent on mutual interference factors among the services sharing the spectrum. The HAPS payload architecture and design provides the flexibility to operate the gateway links virtually anywhere in the 5850-7075 MHz band. The subsequent detailed sharing studies will determine the best location for the HAPS spectrum identification.

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1 See Recommendation ITU-R F.1500 for a more detailed description of these coverage area zones.

2 See Resolution **734 (Rev.WRC-07)**

3 For example, two 34 MHz subchannels with 4 MHz guardbands and each subchannel being FDD or TDD.

It is important to note that the HAPS gateway links spectrum would be in a different frequency band than the individual user links between the HAPS platform and its customer premise equipment (CPE) on the ground as illustrated in Figure 1 above.

2.4 HAPS gateway parameter characteristics

It is assumed that 64 QAM links satisfy the maximum total gateway capacity needed.

Table 4 below provides technical characteristics for 64 QAM 2/3 HAPS system that were used in the elaboration of this report.

Item	UAC - Rain	UAC - Rain	UAC – Clear Sky	UAC – Clear Sky
	TDM down (per carrier)	TDM up (per carrier)	TDM down (per carrier)	TDM up (per carrier)
Bandwidth (MHz)	11	11	11	11
Tx power (dBW)	-22	-19	-22	-19
Tx antenna gain (dBi)	30	47	30	47
Hardware implementation loss (dB)	4.1	4.1	4.1	4.1
Power control gain (dB)	8.0	8.0	0.0	0.0
Nominal e.i.r.p. (dBW)	3.9	23.9	3.9	23.9
e.i.r.p. (dBW) after power control[4]	11.9	31.9	3.9	23.9
Slant range (km)	42	42	42	42
Atmospheric loss (dB)	0.3	0.3	0.3	0.3
Rain attenuation (dB) (99.999% availability)	9.0	9.0	0	0

Table 4: HAPS gateway station parameters taken in the sharing studies in this report (64-QAM modulation)

2.5 Antenna gain pattern

The antenna radiation pattern is a phased array as described in and complies with Resolution **221 (Rev.WRC-07)**. It will be used in both the HAPS gateway (ground) station and in the HAPS (airborne) platform. For the purposes of sharing studies, the gain of the platform and ground station antennas are 30 dBi and 47 dBi, respectively. The antenna radiation pattern mask equation used for the HAPS gateway station and HAPS platform is described in Annex 1 and illustrated in Figure 3 and Figure 4 respectively below.

[4] Nominal e.i.r.p.. denotes the initial power setting. After automatic power control (APC), the TX power is increased by from 0 to up to 8 dB depending on the carrier level.

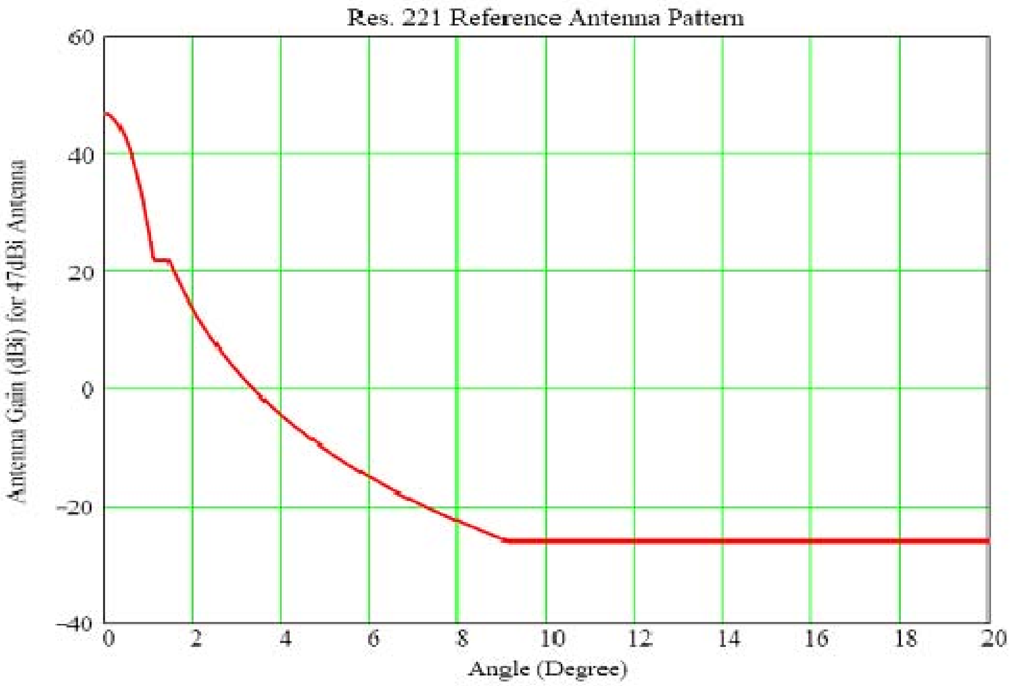


Figure 3: HAPS gateway station reference antenna pattern for 47 dBi antenna

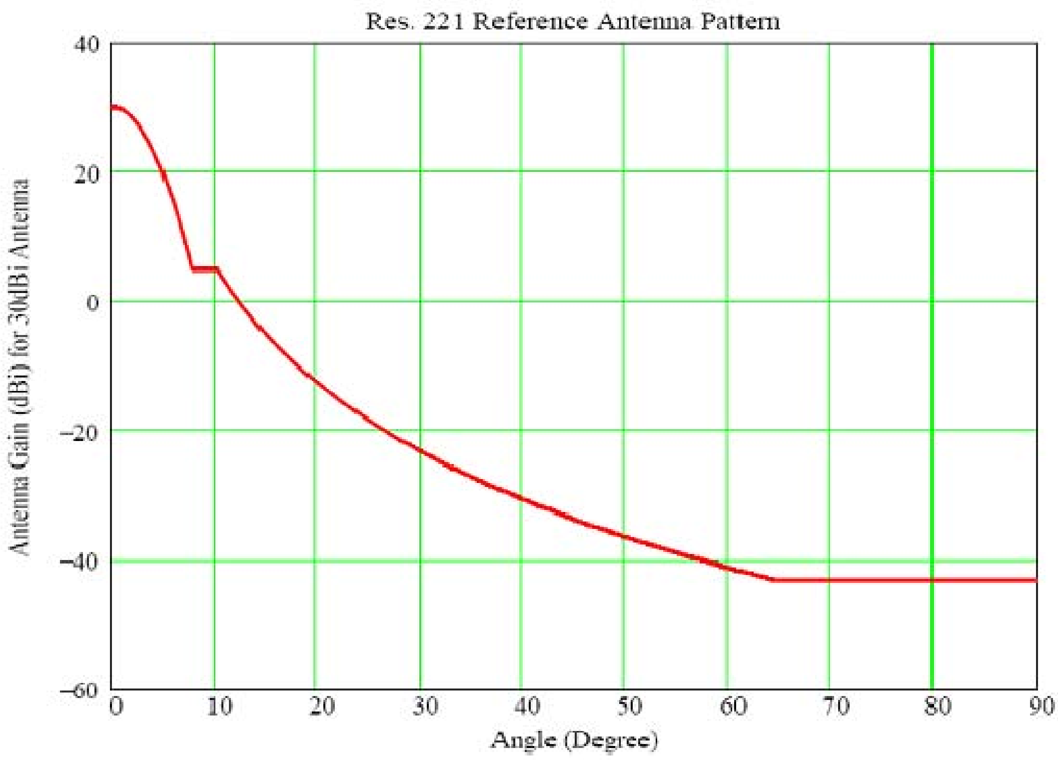


Figure 4: HAPS platform station reference antenna pattern for 30 dBi antenna

3 PROTECTION OF OTHER SERVICES/SYSTEMS TO BE CONSIDERED IN THE STUDIES IN THE BAND 5850-7075 MHz

3.1 Frequency allocations

The frequency allocations in the band 5850-7075 MHz for Region 1 is allocated on a primary basis to FS, FSS, MS. Note that the RAS is referred through footnotes **RR 5.149** and the EESS through **RR 5.458**. The detailed table allocation is presented in Table 25 in Annex 2.

3.2 Technical characteristics of existing systems/services

3.2.1 Fixed service

The FS band is heavily utilized in Europe. The bands are used primarily for backhaul and infrastructure support for many different applications. Recommendation ITU-R F.758-4 [1] contains principles for the development of sharing criteria of digital systems in the fixed service. It also contains information on the technical characteristics and sharing parameters of digital systems for FS.

The technical characteristics of the FS have been extracted from the Table 10 of Recommendation ITU-R F.758 and are given in the Table 5. These values have been considered in the sharing studies since the modulation and the bandwidth correspond to the HAPS characteristics which were taken for the technical studies in this report.

Annex 3 summarizes other FS technical characteristics for other modulation and bandwidth.

Frequency Band (GHz)	5.850-7.075	
Modulation	64-QAM	
Capacity	45 Mbit/s	135 Mbit/s
Channel spacing (MHz)	10	30
Antenna gain (maximum) (dBi)	43	43
Feeder/multiplexer loss (minimum) (dB)	3	3
Antenna type	Dish	Dish
Maximum Tx output power (dBW)	-1	4
e.i.r.p. (maximum) (dBW)	39	44
Receiver IF bandwidth (MHz)		
Receiver noise figure (dB)		
Receiver thermal noise (dBW)	–130	–125
Nominal Rx input level (dBW)		
Rx input level for 1×10^{-3} BER (dBW)	–103	–102
Nominal long-term interference (dBW)	–143 (1)	–138 (1)
Spectral density (dB(W/MHz))	–153	–153
Source	Table 10 of ITU-R Rec.F.758	
(1) Objective for FS systems employing space diversity (I/N = –13 dB).		

Table 5: FS system parameters for sharing in the frequency band 5850-7075 MHz

Recommendation ITU-R F.1245-1 [2] provides a mathematical model of average and related radiation patterns for line-of-sight point-to-point radio-relay system antennas for use in certain coordination studies and interference assessment in the frequency range from 1 to about 70 GHz. This Recommendation may be used in the absence of particular information concerning the radiation pattern of the line-of-sight radio-relay system antennas.

Prior to the study it was essential to define the antenna pattern of FWS antenna. For a FWS functioning at 6 GHz it has been supposed that the antenna diameter was equal to or less than 3 meters. From Recommendation ITU-R F.1245, the ratio between the antenna diameter and the wavelength defines the type of equation that should be used. FWS antenna is located at a height of 6-10 meters above the ground level which appears to be negligible in the calculation of link budget.

Therefore from *Recommends 2.2)* of Recommendation ITU-R F.1245-1 when the ratio between the antenna diameter and the wavelength is less than or equal to 100 ($D/\lambda \leq 100$) the following equation should apply:

$$G(\varphi) = G_{max} - 2.5 \times 10^{-3} \left(\frac{D}{\lambda} \varphi \right)^2 \quad \text{for} \quad 0° < \varphi < \varphi_m$$

$$G(\varphi) = 39 - 5 \log (D/\lambda) - 25 \log \varphi \quad \text{for} \quad \varphi_m \leq \varphi < 48°$$

$$G(\varphi) = -3 - 5 \log (D/\lambda) \quad \text{for} \quad 48° \leq \varphi \leq 180°$$

where:

G_{max}: maximum antenna gain (dBi)

$G(\varphi)$: gain (dBi) relative to an isotropic antenna

φ: off-axis angle (degrees)

D: antenna diameter
λ: wavelength
} expressed in the same unit

G_1: gain of the first side lobe = $2 + 15 \log (D/\lambda)$

$$\varphi_m = \frac{20 \lambda}{D} \sqrt{G_{max} - G_1} \quad \text{degrees}$$

Calculation of antenna gain for a 3 meters dish antenna is presented in Figure 5 while the normalised antenna gain vs off axis angle (i.e. side lobe attenuation) is presented in Figure 6.

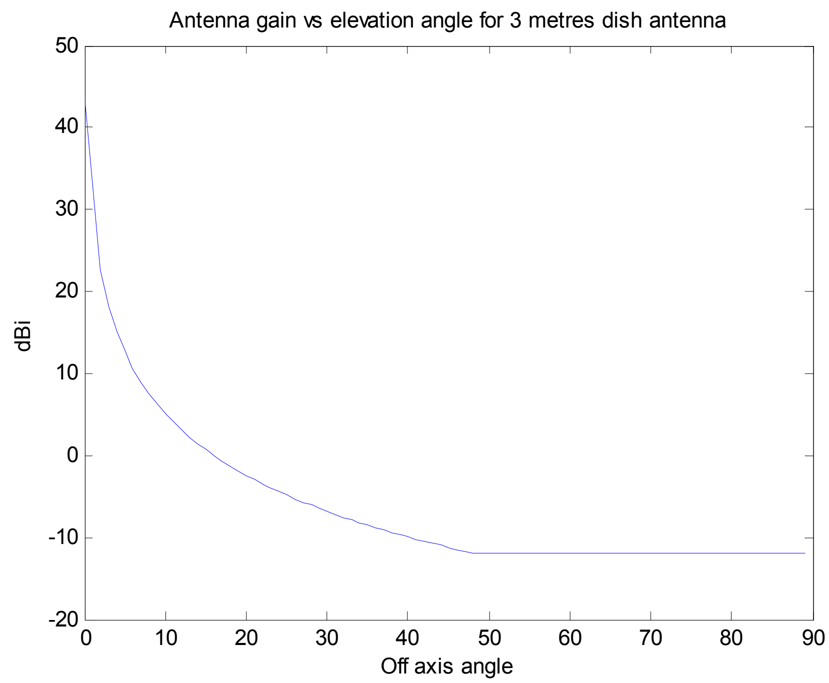


Figure 5: Calculation of antenna gain for a 3 metres dish antenna

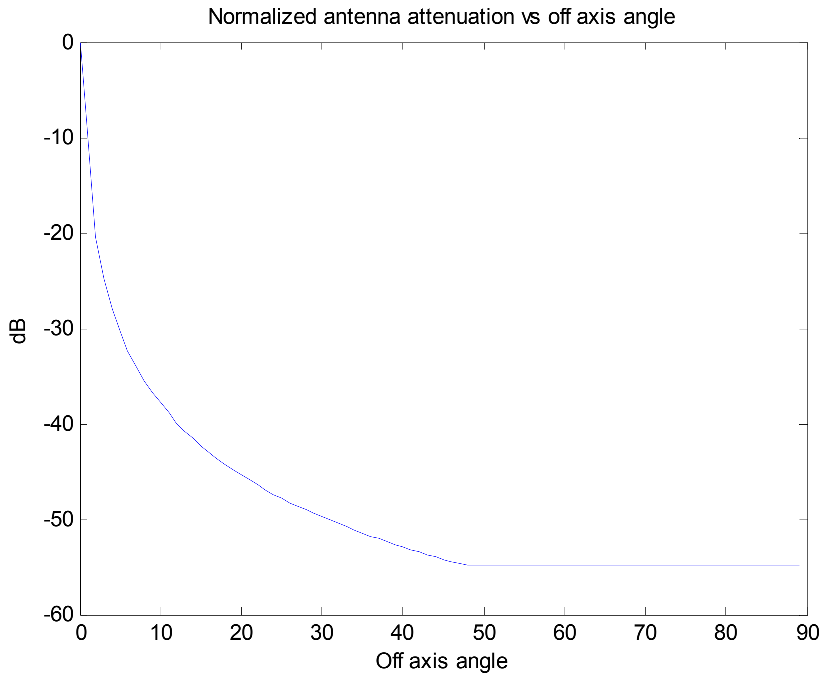


Figure 6: Normalised antenna gain vs off axis angle (side lobe)

3.2.2 Fixed-satellite service (FSS)

3.2.2.1 Non-Plan GSO fixed-satellite service systems

Geostationary FSS space stations at 6 GHz have a typical receive noise temperature of 550 K.

They mainly use 4 types of beams: global, hemispheric, semi-hemispheric and regional. Global beams have a typical antenna gain of 21 dBi, hemispheric beams have a gain of 25 dBi, semi-hemispheric beams have a gain of 30 dBi and regional beams have a gain of 35 dBi. Satellites with smaller national or country coverage may have higher antenna gain levels, especially in the bands governed by the provisions of Appendix 30B. It should be noted that such beams encompass numerous HAPS service areas (i.e. a geographical area served by a HAPS systems).

Typical satellite antenna radiation patterns can be found in Recommendation ITU-R S.672-4 [3].

ITU-R WP 4A suggested using Recommendation ITU-R S.1432-1 [4] as a basis to determine the appropriate permissible levels to protect satellite and earth station receivers. This Recommendation mentions that the portion of “the aggregate interference budget of 32% or 27% of the clear-sky satellite system noise” to be allotted to “other systems having co-primary status” is 6%. Since HAPS are intending to use the fixed service allocation, which is co-primary with the FSS in the band 5850-7075 MHz, while coexisting with the other types of fixed links, the aggregate permissible interference coming from all transmitting HAPS station (either on the ground or the platform) should be no more than 3%.

Table 6 shows the maximum permissible epfd↑ levels to protect geostationary satellite receivers.

	Global beam	**Hemispheric beam**	**Semi-hemispheric beam**	**Regional beam**
f (MHz)	6425	6425	6425	6425
$T_{GSO\ satellite}$ (K)	550	550	550	550
$G_{max\ GSO\ satellite}$ (dBi)	21	25	30	35
$B_{reference}$ (kHz)	4	4	4	4
Aggregate ΔT/T (%)	3	3	3	3
$epfd_{\uparrow,\ aggregate}$ (dBW/(m².4 kHz))	-163.8	-167.8	-172.8	-177.8

Table 6: Derivation of epfd↑ values to protect geostationary satellite receivers

3.2.2.2 FSS Appendix 30B RR allotments

The band 6725-7025 MHz is a part of the range 5850-7075 MHz, and a subject to the provisions of Appendix 30B (FSS Plan) to the Radio Regulations (RR), which sets out the regulatory and technical requirements to be met by FSS networks employing the band.

The FSS Plan (RR Appendix 30B) is intended to preserve orbit/spectrum resources for future use, on an equitable basis among all country members of the ITU. To safeguard the value of the allotted capacity in this Plan, it is important that administrations can implement this capacity at any time that they wish without encountering interference or disruption.

Appendix 30B RR together with corresponding Annexes contains technical characteristics of FSS allotments and establishes relations between FSS networks employing the Appendix 30B RR bands on one hand and systems of the other services having allocations in the bands (currently the FS and the MS) on the other hands.

This FSS Plan is limited with GSO FSS networks only.

It's proposed to consider three real allotments from the FSS Plan. Their names are RUS00001, RUS00003, and RUSLA201. However these allotments have not got the smallest value of Earth station e.i.r.p. density (dB(W/Hz)) mentioned in the Plan. Therefore one more pseudo-allotment XXX00001 was considered additionally with Earth station e.i.r.p. density -9,6 (dB(W/Hz)) and values of major and minor axis of the elliptical cross-section half-power beam of space receiving antenna 1,6 * 1,6 degree. The space receiving antenna of this particular pseudo-allotment XXX00001 may be pointed at any boresight in visible area from the geostationary orbit. Also it is assumed that nominal orbital position of pseudo-allotment XXX00001 is 90 E.

Item	RUS00001	RUS00003	RUSLA201	XXX00001
Earth station e.i.r.p. density (dB(W/Hz))	-7.2	-6.7	-1.4	-9.6
Nominal orbital position, in degrees	61.0	138.5	88.1	90.0
Longitude of the boresight, in degrees	51.5	138.14	94.8	any visible from orbital position 90E
Latitude of the boresight, in degrees	52.99	53.83	48.6	any visible from orbital position 90E
Major axis of the elliptical cross-section half-power beam, in degrees	5.56	5.86	7.5	1.6
Minor axis of the elliptical cross-section half-power beam, in degrees	2.01	2.09	3.5	1.6
Slant distance, km	38724	38749	38284	from 35 786 to 41 670 (it depends on point of boresight)

Table 7: The FSS Plan allotments characteristics for interference modelling

The gain of the Earth station FSS Plan antennas is 50.4 dBi at frequency 6875 MHz (see 1.6.3*bis* Appendix 30B RR). It was assumed that allotment of the FSS Plan is not affected if single-entry carrier-to-interference $(C/I)_u$ value at each test point associated with the allotment under consideration is greater than or equal to a reference value that is 30 dB under free-space conditions (Item 2.1 of Annex 4 Appendix 30B RR).

3.2.2.3 Non-Geostationary FSS satellite

Based upon ITU Space Network Systems database it's proposed to consider the following FSS link of non-GSO MOLNIA-type satellite receiver with lowest noise immunity as the worth case:

Sat.Network / Item	MOLNIA
Frequency, MHz	6200
Inclination angle, degrees	65°
Apogee, km	40 000
Perigee, km	500
Uplink channel bandwidth, MHz	50
Max. peak power, dBW	37
Max. antenna gain, dBi	53
Noise temperature, K	2500

Table 8: Non-GSO FSS networks characteristics for compatibility study

3.2.3 Intelligent transportation systems (ITS)

The frequency band 5855-5875 MHz is identified within CEPT for ITS non-safety applications (see ECC/REC/(08)01 [5]) while the band 5875-5925 MHz is identified for ITS safety-related applications (see ECC/DEC/(08)01 [6]).

Technical and operational characteristics of dedicated short-range communications (DSRC) for ITS at 5.8 GHz have been taken in Recommendation ITU-R M.1453-2 [7] and ECC Report 101 [8] which deals with compatibility studies in the band 5855-5925 MHz between ITS and other systems.

Two kinds of ITS devices[5] are considered:

- OBU (On Board Unit): mobile ITS device mounted on a car.
- RSU (Road Side Unit): fixed ITS device placed on the ground.

The antenna patterns for these two devices are shown in Figure 8 below.

It is an essential design feature of communications between vehicles, or between vehicles and local infrastructure beacons, that they are directed more or less horizontally in a typical omni-directional pattern with typically 8 dBi gain in the horizontal plane.

OBU model is used for the need of the study because it appears as a mobile device mounted on the roof of the car and consequently is the more visible from the HAPS airborne platform and gateway station. The RSU has an elevation angle oriented towards the ground and obviously is less sensible to the interference from HAPS than OBU. Further information on the OBU can be found in ECC Report 101.

Recommendation ITU-R F.1336-2 [9] gives reference models of the peak and average antenna patterns of omnidirectional, sectoral and directional antennas in point-to-multipoint systems to be used in sharing studies in the frequency range 1 GHz to about 70 GHz. The guidance of this recommendation is used in the calculations of this report. It provides the expression of antenna gain in dBi at elevation angle θ in degrees as given below and illustrated in Figure 7:

5 All of the details are taken from ECC Report 101 dealing with compatibility studies in the band 5855– 5925 MHz between ITS and other systems.

$$G(\theta) = \max[G_1(\theta), G_2(\theta)] \quad (1)$$

with

$$G_1(\theta) = G_0 - 12\left(\frac{\theta}{\theta_3}\right)^2 \quad (2)$$

$$G_2(\theta) = G_0 - 12 + 10\log\left[\left(\max\left\{\frac{|\theta|}{\theta_3}, 1\right\}\right)^{-1.5} + k\right] \quad (3)$$

where:

- θ: absolute value of the elevation angle relative to the angle of maximum gain (degrees)
- θ_3: the 3 dB beamwidth in the vertical plane (degrees)
- $k = 1.2$ the sidelobe factor

The relationship between the gain (dBi) and the 3 dB beamwidth in the elevation plane (degrees) is:

$$\theta_3 = 107.6 \times 10^{-0.1 G_0} \quad \text{for omni-directional antenna} \quad (4)$$

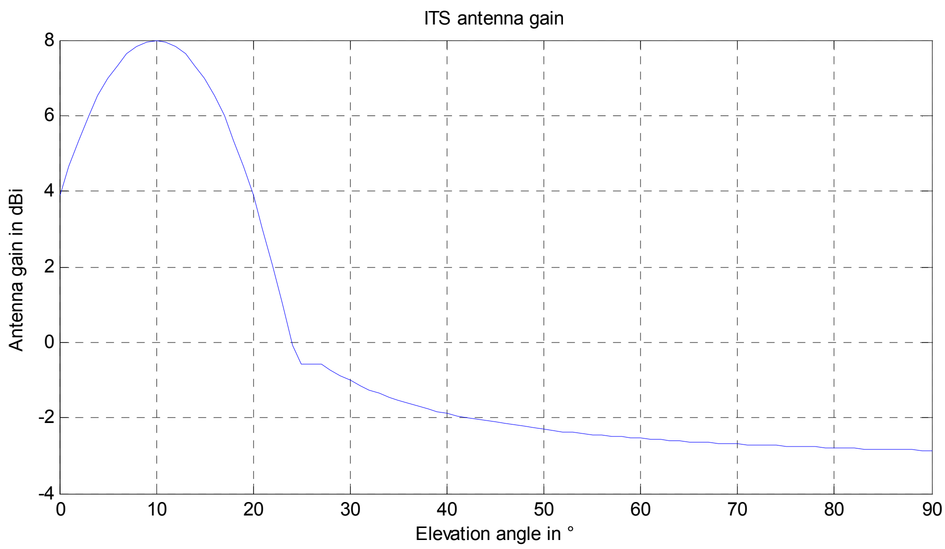


Figure 7: Calculated ITS antenna gain corresponding to elevation angle θ

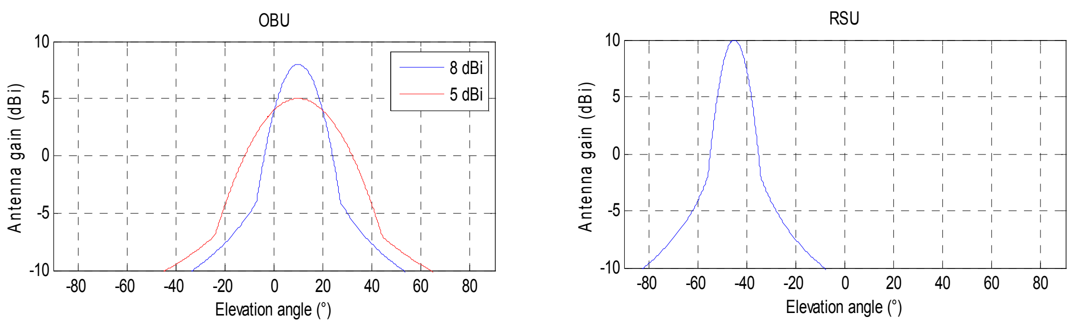


Figure 8: Schema and antenna patterns for OBU and RSU

There are commercially developed, roof mount antennas from 5850 MHz to 5925 MHz. Figure 9 shows that the omni-directionality is fully achieved and the elevation beam peak is near 10°.

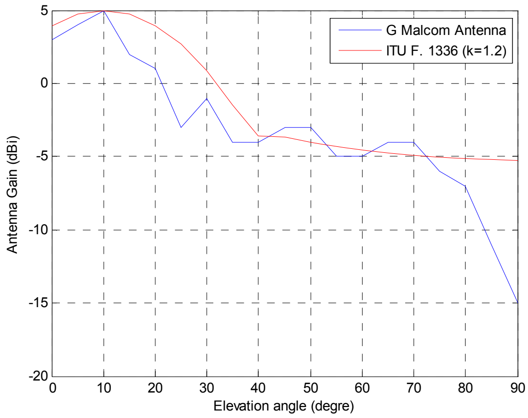


Figure 9: Antenna's pattern with ITU-R F.1336 omni directional pattern

ITS technical parameters used for interference assessment are given in Table 9:

Receiver Characteristics	**Value**	**Units**
Receiver bandwidth	10	MHz
Receiver sensitivity	-82	dBm
Antenna gain (see note 1)	8	dBi
Receiver sensitivity at antenna input	-100	dBm/MHz
C/I	6	dB
Allowable Interfering Power at receiver antenna input	-106	dBm/MHz
Transmitter Characteristics		
Bandwidth	10	MHz
Tx_{out}, e.i.r.p.	33	dBm
Tx_{out} e.i.r.p. per MHz	23	dBm/MHz
Assumed value for TPC	8	dB
Net Tx_{out} e.i.r.p.	15	dBm/MHz
Antenna Gain	8	dBi

Table 9: Technical ITS OBU parameters (ECC Report 101)

Note: The value of 8 dBi is used when considering emissions received or transmitted in the main beam of the ITS.

3.2.4 Earth exploration satellite service (EESS)

The band 6425-7075 MHz is currently used by the passive microwave sensor AMSR-E, which is implemented on the AQUA satellite operated by NASA. Measurements are carried out over the oceans and administrations should bear in mind the needs of the Earth exploration-satellite (passive) and space research (passive) services in their future planning of the band 6425-7025 MHz (**No. 5.458 RR**).

The level of interference to a passive radiometer on board a space station will depend on, among other things, the pointing direction and antenna pattern of the HAPS gateway ground station. If the pointing direction falls within the main lobe of the EESS antenna, the interference level could potentially be high and interference mitigation techniques should be considered. This could result in an area where gateway terminals may not be deployed or other limitations may apply. However, special care should also be taken to the antenna side lobes.

A single passive sensor cannot by itself identify how much energy is radiated by each substance in its field of view. For this reason, data products of most value are derived by comparing measurements from multiple sensors operating at multiple frequencies. By performing radiometric measurements at multiple frequencies, the types of each natural emitter (e.g. water vapor, suspended ice, O_3, etc.) and their concentrations may be derived. As the data from any one sensor may be compared with that of multiple other sensors, any interference received by one sensor may corrupt multiple other measurements.

In combination with other frequency channels, the 6-7 GHz band is essential for observing global soil moisture, global sea surface temperature, temperature of sea ice and sea surface wind through clouds.

Regarding soil moisture, measurements at higher frequencies are strongly influenced by vegetation and the atmosphere, and the 6-7 GHz band is the most suitable for relatively higher spatial resolution measurements. Regarding sea surface temperature, measurements at higher frequencies are strongly influenced by the atmosphere. Furthermore, lower temperatures are more difficult to measure at higher frequencies. For the above reasons, the 6-7 GHz band is the most suitable.

Table 10 summarizes the parameters of passive sensors that are or will be operating in the 6.425-7.25 GHz band. It is copied from the relevant parts of the Recommendation ITU-R RS.1861 [10].

	Sensor B1	**Sensor B2**	**Sensor B3**	**Sensor B4**
Sensor type	Conical scan			
Orbit parameters				
Altitude	705 km	828 km	835 km	699.6 km
Inclination	98.2°	98.7°	98.85°	98.186°
Eccentricity	0.0015	0	0	0.002
Repeat period	16 days	17 days	N/A	16 days
Sensor antenna parameters				
Number of beams	1			
Reflector diameter	1.6 m	2.2 m	0.6 m	2.0 m
Maximum beam gain	38.8 dBi			40.6 dBi
Polarization	V, H			
–3 dB beamwidth	2.2°	1.65°		1.8°
Off-nadir pointing angle	47.5°	46.8°	55.4°	47.5°
Beam dynamics	40 rpm	31.6 rpm	2.88 s scan period	40 rpm
Incidence angle at Earth	55°	55.7°	65°	55°
–3 dB beam dimensions	40 km (cross-track)	24 km		35 km (cross-track)
Instantaneous field of view	43 km × 75 km	68 km × 40 km	112 km × 260 km	35 km × 61 km
Main beam efficiency	95.1%	95%		92%
Swath width	1 450 km	1 700 km	2 000 km	1 450 km
Sensor antenna pattern	See Rec. ITU-R RS.1813			
Cold calibration ant. Gain	25.1 dBi	N/A		25.6 dBi
Cold calibration angle (degrees re. satellite track)	115.5º	N/A		115.5º
Cold calibration angle (degrees re. nadir direction)	97.0º	N/A		97.0º
Sensor receiver parameters				
Sensor integration time	2.5 ms	5 ms	N/A	2.5 ms
Channel bandwidth	350 MHz centred at 6.925 GHz	350 MHz centred at 6.625 GHz	350 MHz centred at 6.9 GHz	350 MHz centred at 6.925 GHz and at 7.3 GHz
Measurement spatial resolution				
Horizontal resolution	43 km	15-50 km	38 km	35 km
Vertical resolution	74 km	24 km	38 km	61 km

Table 10: EESS (passive) sensor characteristics in the 6425-7250 MHz band

According to Recommendation ITU-R RS.1029-2 [11], the interference threshold is −166 dBW for a bandwidth of 200 MHz, which is equivalent to −159 dBm/MHz. This interference criterion has to be understood as an aggregate basis from all sources of interference.

Still according to Recommendation ITU-R RS.1029-2, this criterion may be exceeded less than 0.1% of the time, calculated when the sensor is performing measurements over a reference area of 10 000 000 km². In other words, measurements over only 10 000 km² may be lost due to interference.

Figure 10 shows the AMSR-E antenna diagram applicable when a few interference sources dominate, which is the case of HAPS since the number is supposed to be limited. This is given in Recommendation ITU-R RS.1813 [12].

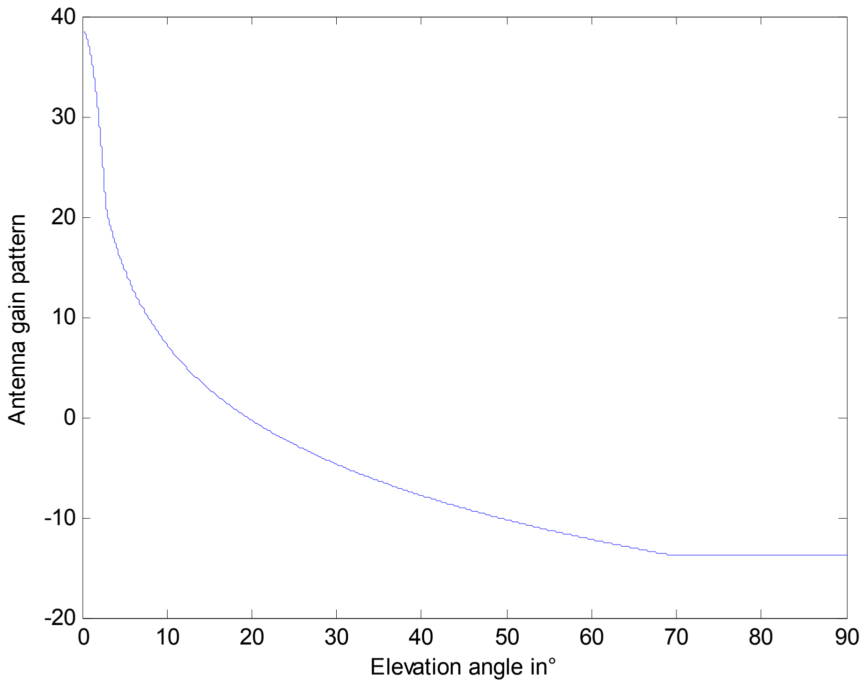


Figure 10: AMSR-E antenna gain pattern

3.2.5 Radioastronomy service

In Europe, to this date, the band 6650-6675.2 MHz is used by the Radio Astronomy Service in Finland, Germany, Italy, Netherlands, Poland, Spain, Sweden, Turkey, United Kingdom as summarised in Table 11. In the last years this band became very important for the European scientific community and especially for European VLBI Network (EVN) and Multi-Element Radio Linked Interferometer Network (MERLIN). That is why, in the future, it is expected that this band will be used by some other countries, too.

Country	Location	Coordinates	Antenna	Altitude above sea level
Finland:	Metsähovi	24° E 23'37" ; 60° N 13'04"	14 m	61 m
Germany:	Effelsberg	06° E 53’ 00”; 50° N 31’ 32”	100 m	369 m
Italy:	Sardinia*	09° E 14’ 40”; 39° N 29’ 50”	64 m	650 m
	Medicina	11° E 38'49" ; 44° N 31'14"	32 m	28 m
Netherlands:	Westerbork	06° E 36'15" ; 52° N 55'01"	14 x 25 m	16 m
Poland:	Torun	18° E 33’ 30”; 52° N 54’ 48”	32 m / 15 m	100 m
Spain:	Yebes	03° W 05’ 22”; 40° N 31’ 27”	40 m / 14 m	981 m
Sweden:	Onsala**	11° E 55’ 35”; 57° N 23’ 45”	25 m / 20 m	10 m
Turkey:	Kayseri	36° E 17’ 58”; 38° N 59’ 45”	5 m	1054 m
United Kingdom***:	Jodrell Bank	02° W 18'26"; 53° N 14'10"	76 m / 13 m	78 m
	Cambridge	00° E 02'20"; 52° N 09'59"	28 x 25 m / 32 m	24 m

Table 11: Radio astronomy stations in Europe using frequencies between 6 and 7 GHz

Note: ** The Sardinia Radio Telescope is still under construction*

*** The Onsala observatory is very close to the sea*

**** In UK, because of some national reasons, not all radio astronomy stations may be included under the footnote* ***5.149 RR***.

Protection criteria used for radio astronomical measurements contains in the Recommendation ITU-R RA.769-2 [13]. Methodology of protection of the radio astronomy service in frequency bands shared with other services can be found in Recommendation ITU-R RA.1031-2 [14].

Threshold levels of interference detrimental to radio astronomy spectral-line observations in the band 6.67 GHz is -230 dB($Wm^{-2}Hz^{-1}$). This value is derived with methodology described by Recommendation ITU-R RA.769 for an antenna side lobes gain of 0 dBi, assuming that interferences reach the radio telescope through side lobes. This might be not fully true in case of HAPS (airborne station (or downlink)) emissions, when the interference can reach the radiotelescope via antenna main lobe, requiring that a part of the antenna main lobe gain to be considered in the assessment.

4 METHODOLOGY – INTERFERENCE MODELLING

4.1 Fixed service

4.1.1 Interference from HAPS airborne station into FWS

During HAPS vs FS sharing it needs to take into account the present and future usage of the bands by the FWS, the system parameters used, the interference criterion and the ability of the proposed HAPS gateway stations to limit interference to the allowable values. Interference from HAPS gateway links can be minimized, taking into account minimum required pointing and elevation angles from the gateway stations, this includes use of highly directive antennas on the HAPS platforms.

Interference from HAPS gateway downlinks can be minimized by taking into account high directivity antennas on the platforms. Taking into account FWS system parameters, it would be possible to mitigate the interference by HAPS platforms through the use of specific coordination area or power flux-density limits.

The methodology consists in the calculation of the maximum *eirp* at HAPS airborne antenna output to satisfy a FWS nominal long term interference criterion of -143 dBW/10 MHz at receiver antenna input (see Table 5). It is supposed that FWS can be located anywhere in the UAC. The HAPS platform is located at an altitude of 21 kilometers. FWS antenna is considered at ground level and at a height of 10 meters which appears to be negligible in the calculation of free space loss (FSL) attenuation (altitude of 20990 m for HAPS platform instead of 21000 m). For this study provisionally a I/N of -13 dB was considered which is one of the value used for co-primary sharing.

However, permissible interference levels from HAPS should take into account the already required allowances for sharing between other FS, and sharing with FSS uplinks, as well as MSS feeder links. Given current FS interference budgets requirements, there may be very little margin for additional interference entries in the band. Although HAPS is a recognized service in the FS, according to RR 4.15A it is only useable in bands expressly identified by the Table of Frequency Allocations. The interference introduced by such systems should therefore only be accommodated within the interference allocations for the FS.

If HAPS is to be introduced into bands already heavily used, a maximum of 10% of the co-service allowance might be considered. Recommendation ITU-R F.1094 [15] apportions allowable interference in the primary bit-rate services to the FS, other services and other emissions respectively as 89%, 10% and 1% of the total interference allowance. Allowing 20% degradation due to total interference, this means that the FS allowance is 17.8% of the error performance objectives. The HAPS allotment would then be 1.78% of the error performance objective, leading to an allowable I/N of –17.5 dB.

Therefore the maximum HAPS station *eirp* to protect FWS receivers is a function of two variables:

- elevation angle θ,
- distance *D* between the HAPS station and the FWS receiver antenna which has 0 degree of elevation angle (see Figure 11 below).

From HAPS airborne platform towards the ground the offset angle from nadir varies between 0° (nadir) and 60° to cover the UAC footprint.

The distance “D” corresponding to an offset angle of 60° is 42 km.

The methodology assumes that a single HAPS platform is in visibility of the FWS P-P in co-frequency at 6500 MHz which could be considered as a medium range frequency in the band 5850-7075 MHz. The computation has also been performed at the edge of the band for the minimum frequency 5850 MHz and for the maximum frequency 7075 MHz.

The FWS P-P is equipped with an antenna which has a diameter less than 3 meters and 43 dBi gain. Cable loss is 3 dB.

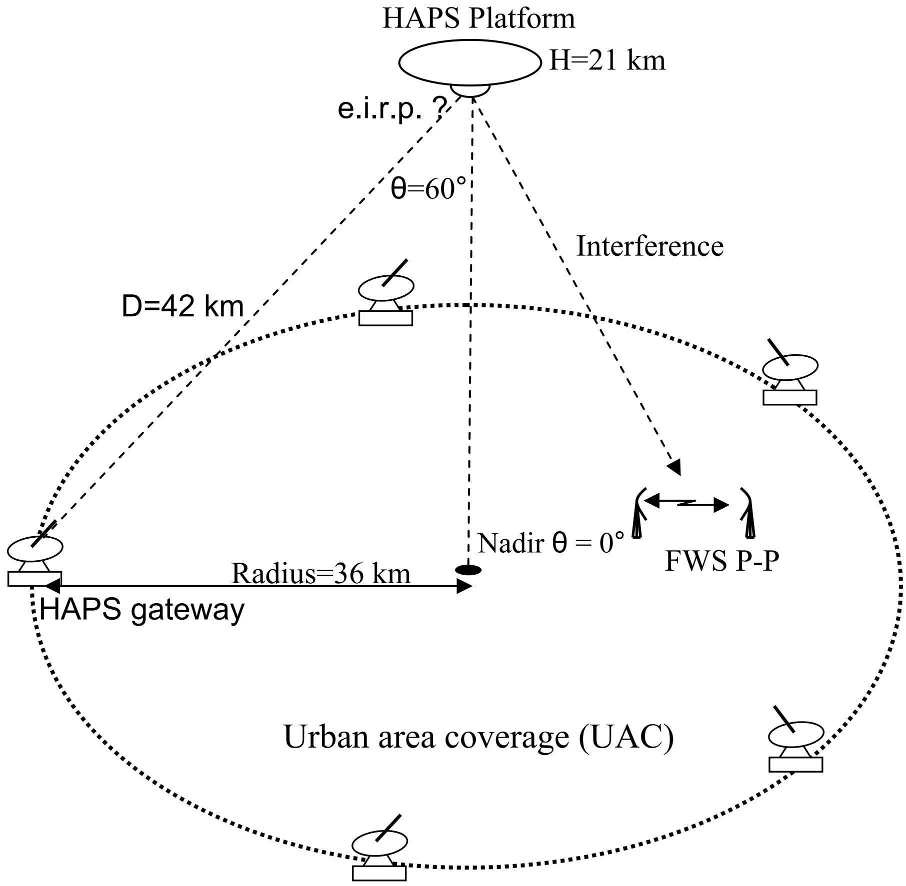


Figure 11: Methodology HAPS airborne platform vs FWS P-P (figure not to scale)

The maximum *eirp* for HAPS must satisfy the retained nominal long term interference (I=-147.5dB/10 MHz) for FWS as given by the following equation:

$$EIRP_{HAPS} - FSL_{HAPS} + G_{FWS} - Att_{Side\ lobe\ FWS} - L_{Feeder\ FWS} < I \quad (5)$$

From (5) the maximum *eirp* is:

$$EIRP_{HAPS} < I + FSL_{HAPS} - G_{FWS} + L_{Feeder\ FWS} + Att_{Side\ lobe\ FWS} \quad (6)$$

where:

- $EIRP_{HAPS}$: maximum *eirp* at HAPS airborne antenna output to satisfy a FWS allowable interfering power criterion of -143 dBW/10 MHz at receiver antenna input (I/N=-17.5 dB);
- FSL_{HAPS} : free space loss at 6500 MHz (dB);
- G_{FWS}: max antenna gain of FWS antenna (dBi) according to Recommendation ITU-R F.758-4;
- $Att_{Side\ lobe\ FWS}$: side lobe attenuation for FWS antenna has been calculated with parameters from Recommendation ITU-R F.1245-1;
- $L_{Feeder\ FWS}$: Feeder loss for FWS antenna (see Table 5).

4.1.2 Interference from HAPS gateway station into FWS

The methodology consists in the calculation of the minimum separation distance "D" between a HAPS gateway station and the FWS P-P system that may be deployed anywhere inside an UAC. The minimum distance "D" is calculated to be compliant with the maximum long-term interference of -147.5 dBW/10 MHz (I/N=-17.5dB) (Figure 12).

Attenuation in side lobe for FWS P-P antenna has been computerized from Recommendation ITU-R F.1245 (Figure 5 and Figure 6 above).

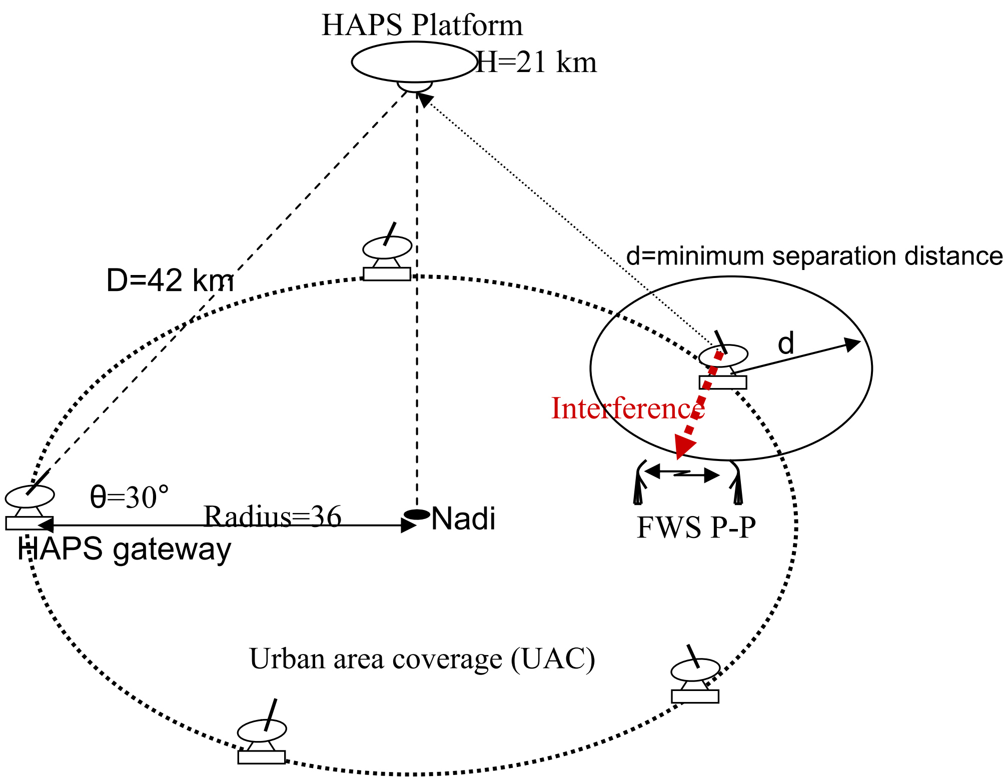


Figure 12: Interference modelling scenario HAPS gateway towards FWS P-P

$$D=10^{(Att.r-32.44-20\log F)/20}$$

where :

- D: is minimum separation distance for allowable interfering power at receiver antenna inpout (km);
- Att.r: is the required attenuation at the minimum distance calculated in the Table 12 below;
- F: frequency (MHz).

4.2 Fixed satellite service

4.2.1 Interference from HAPS (airborne and ground station) to non-Plan GSO fixed-satellite service systems

Protection of geostationary FSS satellite receivers (non FSS Plan of Appendix 30B RR) in the band 5850–7075 MHz can be achieved through the limitation of maximum permissible e.i.r.p. levels from HAPS stations (either on the ground or the platform) towards the geostationary arc. It should be noted that the methodology is based on the protection required by satellite receivers and is independent of HAPS characteristics, except for the derivation of single-entry permissible e.i.r.p. levels where the number of expected HAPS stations simultaneously transmitting within the coverage area of a geostationary satellite is used.

The following formula allows determining the epfd levels to protect geostationary satellite receivers from the aggregate interference caused by all transmitting stations into a high-altitude platform system:

$$epfd_{\uparrow} = 10\log\left(kT_{GSO\ satellite}B_{reference}\frac{\Delta T}{T}\right) - G_{max\ GSO\ satellite} + 10\log\left(\frac{4\pi}{\lambda^2}\right)$$

where:

- k: Boltzmann’s constant;
- $T_{GSO\ satellite}$: Geostationary satellite receiver noise temperature;

- $B_{reference}$: Reference noise bandwidth (consistent with Recommendation ITU-R S.524-7, the epfd levels are proposed to be expressed per 4 kHz);
- $\Delta T/T$: Level of permissible interference from HAPS stations into satellite receivers (it can be either an aggregate or single-entry level);
- $G_{max\ GSO\ satellite}$: Maximum gain of a geostationary satellite beam;
- λ: wavelength.

The typical value for all parameters as well as the maximum permissible epfd↑ levels to protect geostationary satellite receivers can be found in Table 6.

Since the uplink equivalent power flux-density (epfd↑) is the sum of the power flux-densities produced at a geostationary satellite receiver, by all the transmit stations within a HAPS system, taking into account the off-axis discrimination of the receiving antenna, the epfd↑ levels can also be expressed as:

$$epfd_{\uparrow} = 10\log\left[\sum_{i=1}^{N_{HAPS}} \frac{e.i.r.p.(\theta_i)}{4\,\pi\, d_i^2} \cdot \frac{G_{GSO}(\varphi_i)}{G_{GSO,\,max}}\right]$$

where:

- N_{HAPS}: number of transmit stations (either on the ground or on platforms) in the HAPS system that are simultaneously transmitting within the coverage area of the geostationary satellite
- θ_i: off-axis angle between the boresight of the transmit station in the HAPS system and the direction of the geostationary satellite receiver
- e.i.r.p. (θ_i): e.i.r.p. transmitted by the i^{th} station in HAPS system in the direction of the geostationary satellite
- d_i: distance between the i^{th} transmit station in the HAPS system and the geostationary satellite
- φ_i: off-axis angle between the boresight of the antenna of the geostationary satellite receiving beam and the direction of the i^{th} transmit station in the HAPS system
- $G_{GSO}(\varphi_i)$: antenna gain of the geostationary satellite receiving beam in the direction of the i^{th} transmit station in the HAPS system
- $G_{GSO,max}$: maximum gain of the antenna of the geostationary satellite receiving beam.

Assuming a constant value for the distance *d* between the HAPS transmit stations and the geostationary satellite and, for a first assessment, neglecting the impact of HAPS stations outside of the area where the gain of the satellite antenna is relatively constant and close to the maximum gain, the previous formula can be simplified in:

$$epfd_{\uparrow} \approx 10\log\left(\sum_{i=1}^{N_{HAPS}} e.i.r.p.(\theta_i)\right) - 10\log\left(4\,\pi\, d^2\right)$$

and, since a maximum off-axis e.i.r.p. radiated by each HAPS station is sought to be computed:

$$epfd_{\uparrow} \leq e.i.r.p._{maximum\ off\text{-}axis,\ HAPS} + 10\log(N_{HAPS}) - 10\log\left(4\,\pi\, d^2\right)$$

In order to protect the geostationary satellite receivers, the produced uplink epfd shall be less than the required aggregate uplink epfd values computed in Table 13. To ensure this, it is sufficient to guarantee that the following:

$$e.i.r.p._{maximum\ off\text{-}axis,\ HAPS} \leq epfd_{\uparrow,\,aggregate} + 10\log\left(4\,\pi\, d^2\right) - 10\log(N_{HAPS})$$

4.2.2 Interference from HAPS (airborne and ground station) to FSS Appendix 30B RR allotments

Due to the fact that there is only FSS Plan uplink in the band 6725-7025 MHz the following interference scenarios were studied:

Scenario 1

Interference from HAPS gateway (ground) station into FSS network satellite receiver (Figure 13).

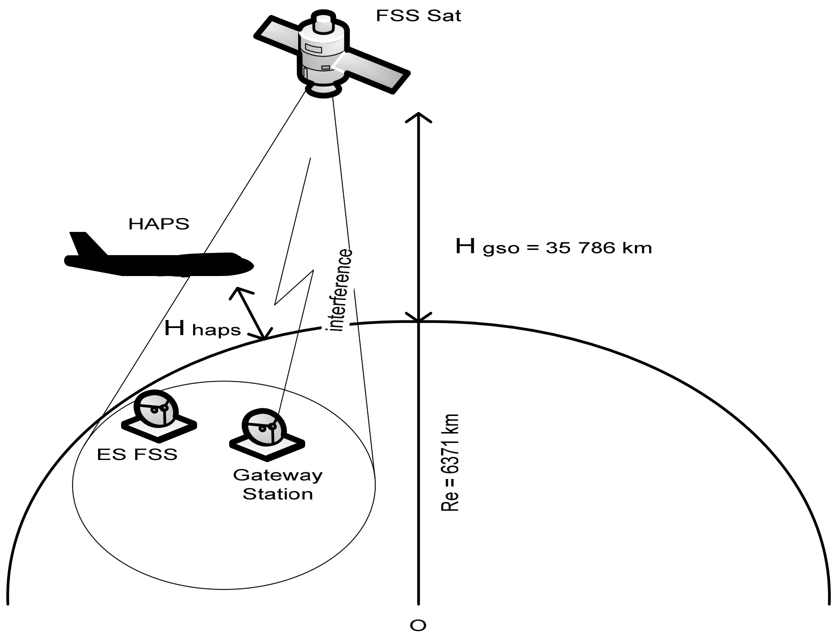


Figure 13: Interference from HAPS gateway (ground) station into FSS network satellite receiver

Scenario 2

Interference from HAPS platform station into FSS network satellite receiver. It may be 2 different sub-scenario in this case. A sub-scenario 2a is shown at Figure 14 and a sub-scenario 2b is at Figure 15.

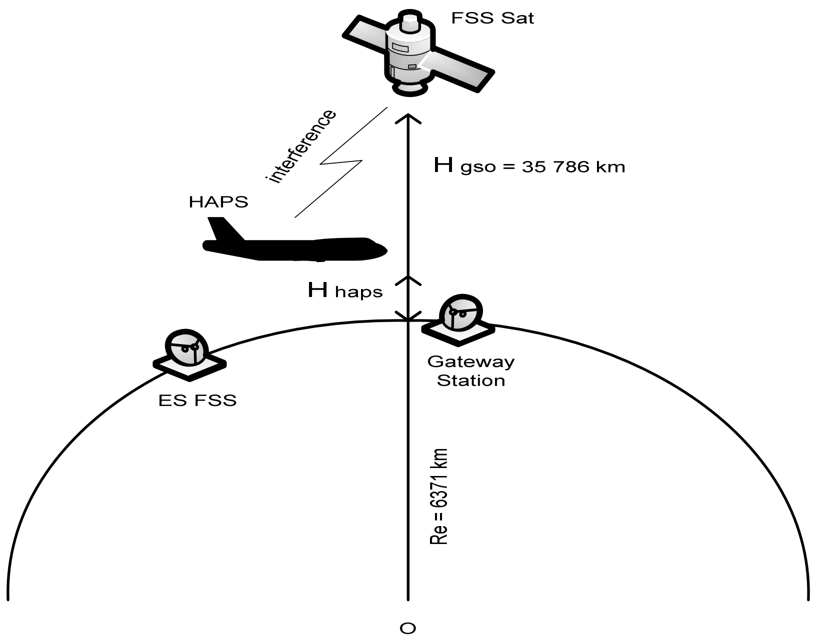


Figure 14: Interference from HAPS platform station into FSS network satellite receiver (Sub-scenario 2a)

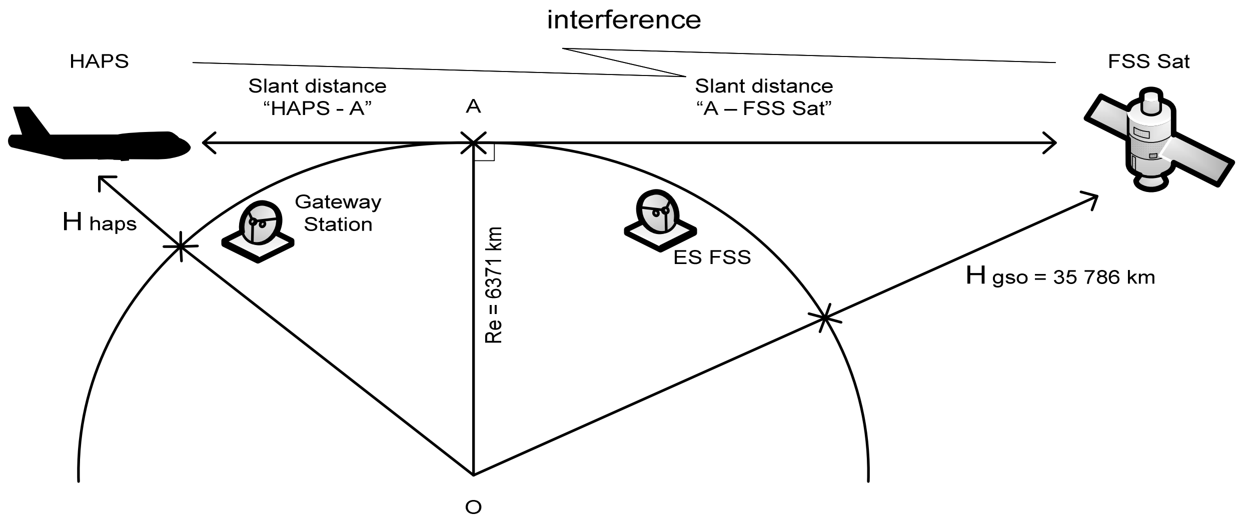


Figure 15: Interference from HAPS platform station into FSS network satellite receiver (Sub-scenario 2b)

It's assumed in all scenarios that interference penetrates to the FSS Plan allotment through the main beam of space receiving antenna and therefore the signal and interference paths are the same.

4.2.3 Interference from HAPS (airborne and ground station) to non-geostationary FSS satellite

In purpose of simplification of non-GSO interference calculation the scenarios for FSS Plan allocations in compliance with free space loss may be used, while the slant distance between non-GSO satellite and Earth station is derived from Figure 16 as

$$d = (h + R_e)\cos(\varepsilon + \delta)/\cos\varepsilon\,,$$

where *h* – the non-GSO satellite altitude, km, ε - the Earth station elevation angle, degrees, and

$$\delta = \arcsin\left(\frac{R_e \cos\varepsilon}{h + R_e}\right).$$

For worth case consideration it's assumed that the lowest Earth station elevation angle is 5°, while HAPS is allocated in direct visibility of the satellite at the apogee (h = 40 000 km).

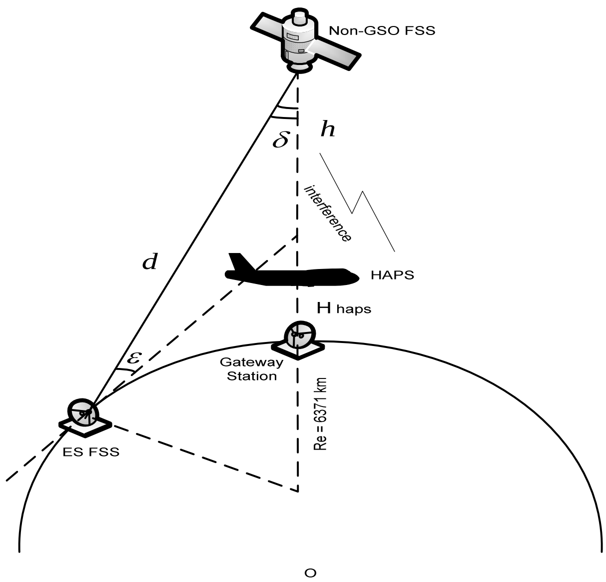


Figure 16: Interference from HAPS platform/gateway station into non-GSO FSS network satellite receiver

Thus the following scenarios are considered:

- Scenario 1 - Interference from HAPS gateway (ground) station into non-GSO FSS network satellite receiver;
- Scenario 2a - Interference from HAPS platform station (back-lobe) into non-GSO FSS network satellite receiver;
- Scenario 2b - Interference from HAPS platform station (main-lobe) into non-GSO FSS network satellite receiver (Figure 17).

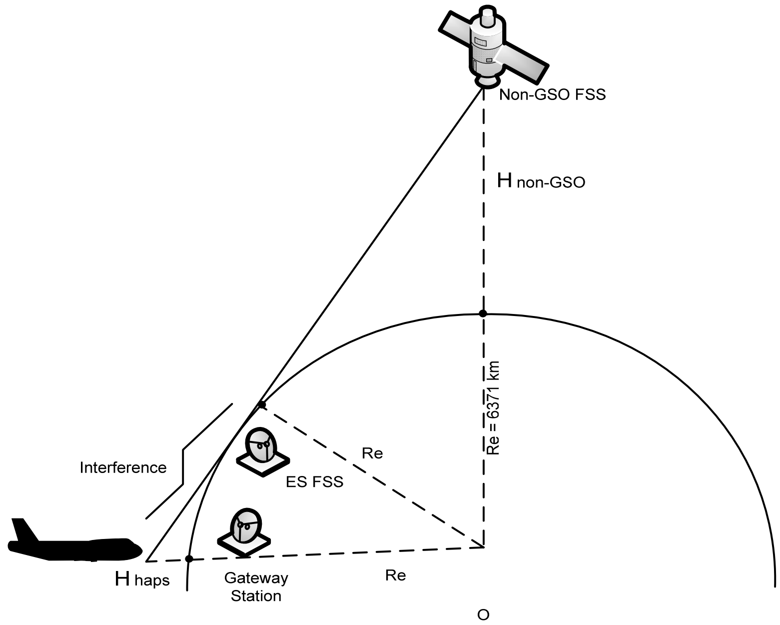


Figure 17: Interference from HAPS platform station (main-lobe) into non-GSO FSS network satellite receiver

It's assumed in all scenarios that interference penetrates to non-GSO FSS satellite receiver through the main beam of space receiving antenna. It's also should be noted that required C/I ratio is derived in compliance with Recommendation ITU-R S.740 as

$$C / I = C / N + 12.2 dB .$$

The noise power N is defined as

$$N = k + 10(\lg T_s + \lg B_{wup}),$$

where B_{wup} - the uplink channel bandwidth, Hz; k – the Boltzmann constant -228.6 dB(J/K); T_s - the satellite receiver noise temperature, K.

Calculation for all scenarios was made under free-space conditions.

4.3 Intelligent transportation systems (ITS)

4.3.1 Interference from HAPS airborne station emissions into ITS receiver.

The methodology consists in the calculation of the maximum e.i.r.p. at HAPS airborne antenna output to satisfy the ITS allowable interfering power criterion of -106 dBm/MHz (or -136 dB/MHz) at receiver antenna input defined in ECC Report 101 (see Table 9).

It is supposed that ITS antenna is mounted on the roof of a car circulating on a flat road and at ground level. The car can be located anywhere in the urban area coverage (UAC).

The HAPS platform is located at an altitude of 21 kilometres.

Therefore the maximum HAPS station e.i.r.p. to protect ITS receivers is a function of two variables as shown in Figure 18:

- elevation angle θ,
- distance "D" between the HAPS station and the ITS receiver .

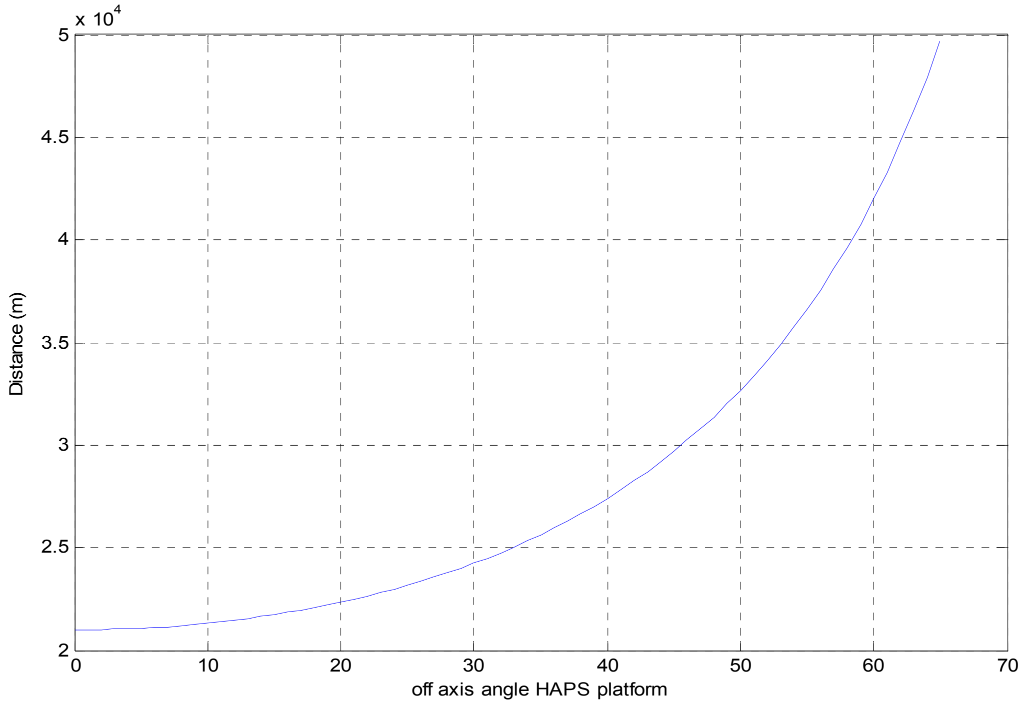


Figure 18: distance vs off-axis angle in UAC

From HAPS airborne platform towards the ground the elevation angle of interfering signal varies between 0° (nadir) and 60° to cover the UAC footprint. The distance "D" corresponds to slant range of 42 km.

The methodology (Figure 19) assumes that a single HAPS platform is in visibility of the ITS device in co-frequency at 5900 MHz.

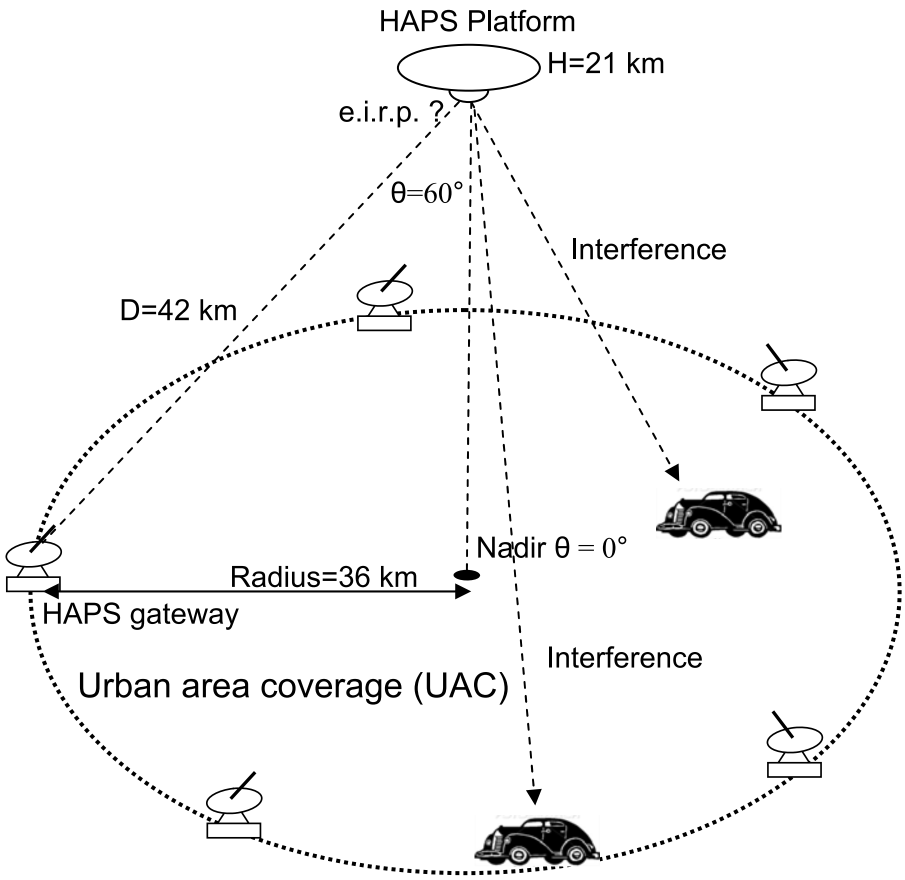


Figure 19: Methodology HAPS aeronautical platform vs ITS

The maximum *e.i.r.p.* for HAPS must satisfy the protection criterion for ITS as given by the following equation:

$$EIRP_{HAPS} - FSL_{HAPS} + G_{ITS} < -106 dBm/MHz \qquad (7)$$

From (7) the maximum *eirp* is:

$$EIRP_{HAPS} < -106 + FSL_{HAPS} - G_{ITS} \qquad (8)$$

where*:*

- $EIRP_{HAPS}$: maximum *eirp* at HAPS airborne antenna output to satisfy the ITS allowable interfering power criterion of -106 dBm/MHz (or -136 dB/MHz) at receiver antenna input;
- FSL_{HAPS} : free space loss at 5900 MHz (dB);
- G_{ITS}: antenna gain of ITS OBU antenna (dBi) according to Recommendation ITU-R F.1336.

4.3.2 Interference from HAPS gateway station emissions into ITS receiver

The methodology (Figure 20) consists in the calculation of the minimum separation distance “D” between a HAPS gateway station and an ITS OBU device that may be deployed anywhere inside the UAC. Minimum calculated distance must satisfy the protection criterion of -106 dBm/MHz (or -136 dB/MHz).

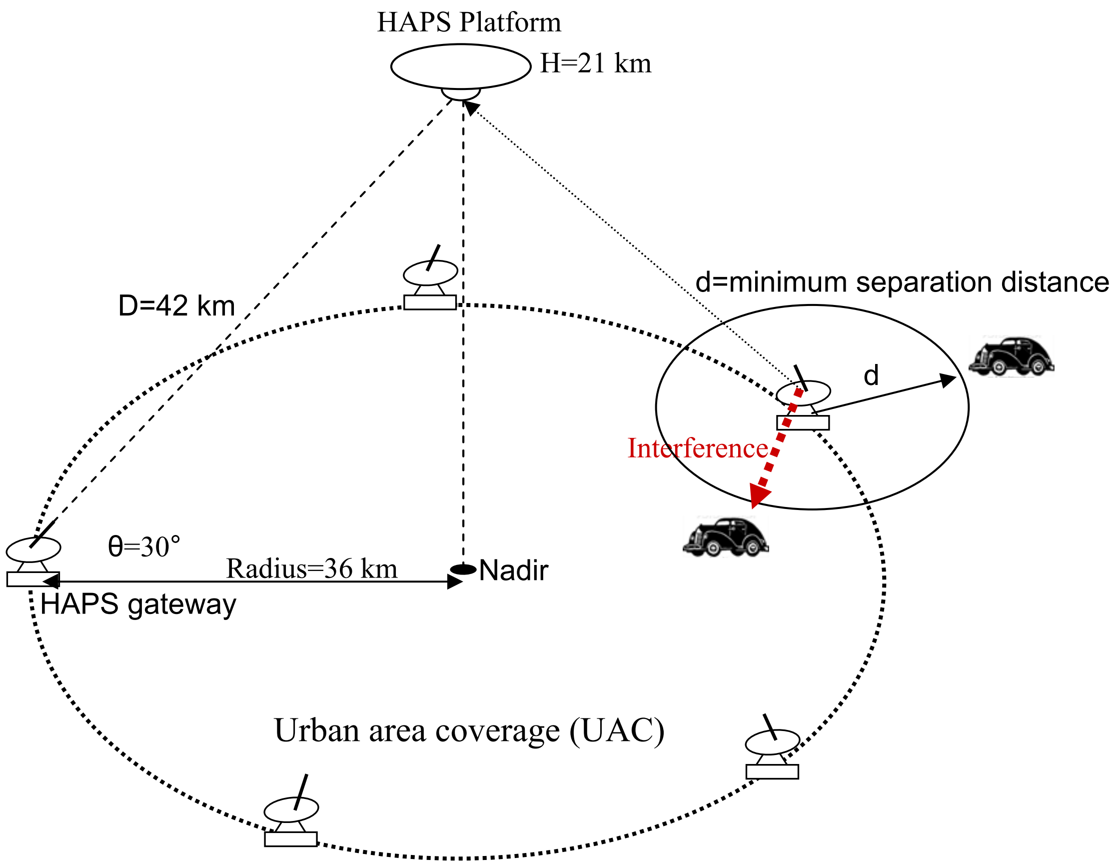


Figure 20: Methodology HAPS gateway station vs ITS

$$D = 10^{(Att.r - 32.44 - 20 \log F)/20}$$

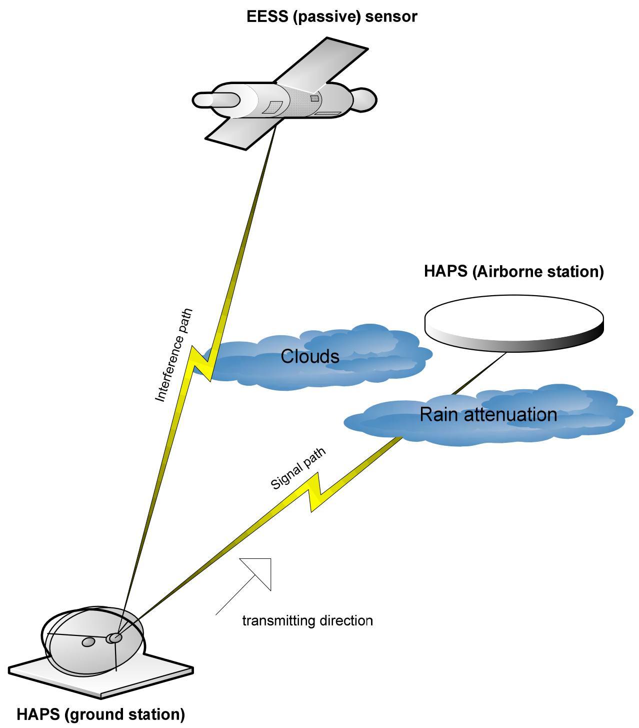
where :

- D: is minimum separation distance for allowable interfering power at receiver antenna in pout (km),
- Att.r: is the required attenuation at the minimum distance calculated in Table 20 (dB),
- F: frequency (MHz).

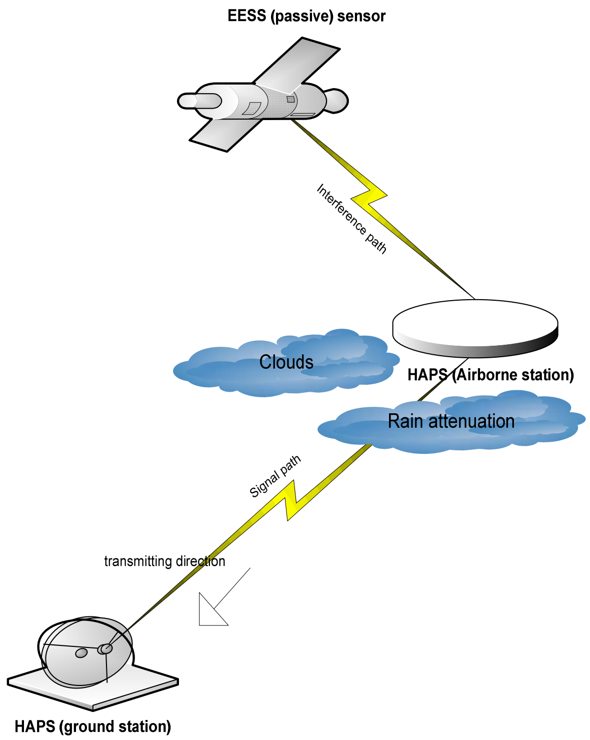
4.4 Earth exploration satellite service (EESS)

As explained in Section 2.3, the HAPS gateway links have two 80 MHz channels in the 5850-7075 MHz band. Each 80 MHz channel may divide into six equally spaced 11 MHz subchannels separated by 2 MHz guardbands and all of these sub–channels, within each 80 MHz bandwidth, are always utilized in the same direction. Due to the fact that passive microwave sensor measurements are carried out over the oceans in the band 6425-7075 MHz the following sharing scenarios should be considered:

Scenario 1: Only HAPS gateway links (uplink) overlap with EESS (passive). The HAPS uplink case represents obviously the most critical sharing scenario with EESS (passive), given the fact that the EESS (passive) sensors look down in the direction of the Earth surface with angles that are in the same range of the elevation angles of the HAPS gateway main beam antenna.



Scenario 2: Only HAPS gateway links (downlink) overlap with EESS (passive).



Scenario 3: Both HAPS gateway links (up and downlink) overlap with EESS (passive). This Scenario needs to be consider only in the case if there is no interference in the Scenarios 1and 2. If either Scenario 1 or 2 the EESS (passive) protection criteria exceed thus this criteria will be exceeded in Scenario 3.

The following formula to be applied for all kind of sharing scenarios for static and dynamic simulation:

$Pt_{HAPS} + Gt_{HAPS}(\theta) - Ls + Gr_{EESS}(\varphi) < -166$ dBW (sensor protection level, see Recommendation ITU-R SM.1029)

where: Pt_{HAPS} = Total transmitter power

$Gt_{HAPS}(\theta)$ = Transmitter gain

Ls = Space loss

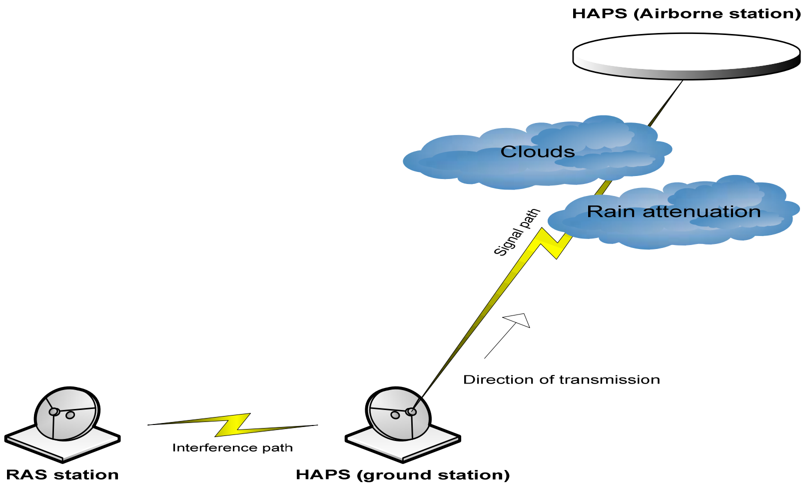
$Gr_{EESS}(\varphi)$ = Receiver gain

4.5 Radioastronomy service

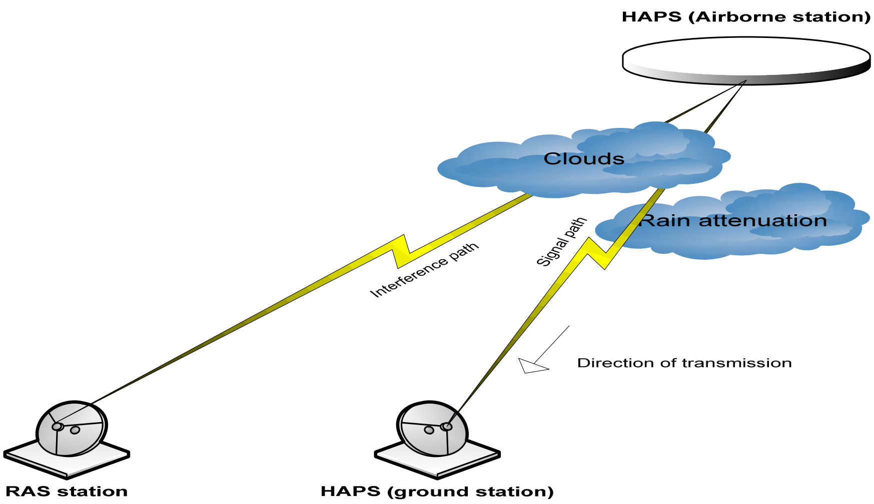
The methodology consists in the calculation of the minimum separation distance "R" between a HAPS gateway station and/or airborne platform and an RAS observatory. According to the Recommendation ITU-R RA.769 the detrimental threshold level for RA spectral-line observations in the band 6650-6675.2 MHz is -230 $dBWm^{-2}Hz^{-1}$. Therefore the minimum calculated distance must satisfy this protection criterion.

Two sharing scenarios should be considered.

Scenario 1: Only HAPS gateway links (uplink) overlap with RAS.



Scenario 2: Only HAPS gateway links (downlink) overlap with RAS.



The following formula to be applied for both sharing scenarios:

$SPt_{HAPS} + Gt_{HAPS}(\theta) - Ls - Lrain + Gr_{RAS}(\varphi) < -230$ $dBWm^{-2}Hz^{-1}$ (Threshold interference level (spectral pfd), see Recommendation ITU-R RA.769)

where: SPt_{HAPS} = Spectral transmitter power, including power control gain

$Gt_{HAPS}(\theta)$ = Transmitter gain

Ls = Space loss

Lrain = Rain attenuation

Gr_{RAS} (φ) = Receiver gain

Therefore $SPt_{HAPS} + Gt_{HAPS}(\theta) + Gr_{RAS}(\varphi) - Lrain + 230\ dBWm^{-2}Hz^{-1} < Ls$

$$R <= 10^{(Ls-10\log(4*PI))/20}$$

where :

- R: is minimum separation distance for allowable interfering power at receiver antenna in pout (m).

5 RESULTS OF STUDIES

5.1 HAPS vs FS

5.1.1 Interference from HAPS (airborne platform) (downlink) into conventional FWS

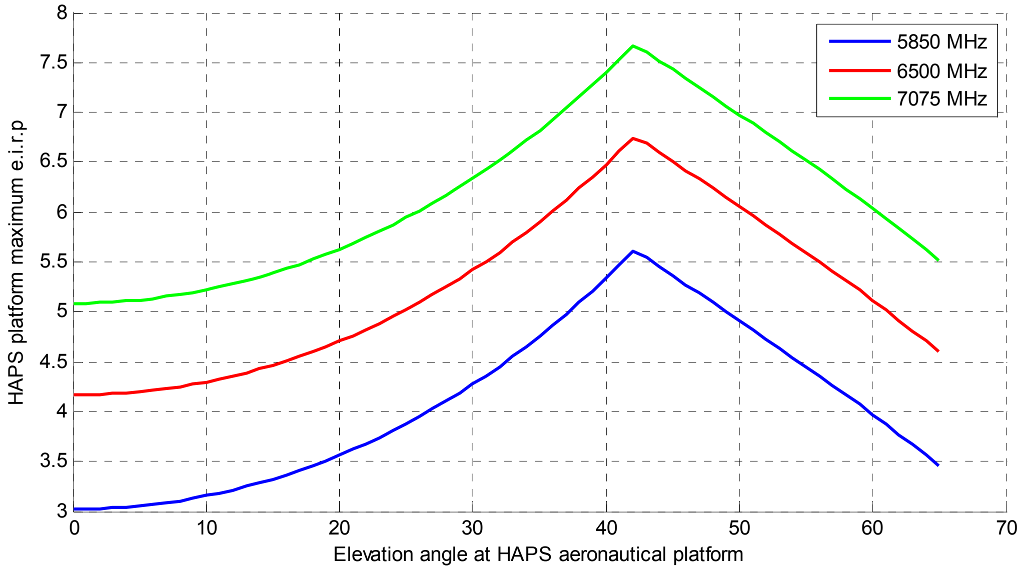


Figure 21: calculated maximum e.i.r.p. in dBW at HAPS platform for 5850 MHz, 6500 MHz and 7075 MHz

Figure 21 shows the maximum *eirp* at HAPS airborne antenna output to satisfy a FWS nominal long-term interference of -143 dBW/10MHz at receiver antenna input of a FWS P-P that is supposed to be deployed anywhere in an UAC, from the centre towards the edge of the cell and corresponding to an off-axis angle at the HAPS platform varying from 0° to 60°.

Figure 21 points out three different curves corresponding respectively to frequencies 5850 MHz, 6500 MHz, and 7075 MHz. For the need of the sharing study only the medium value of 6500 MHz and corresponding maximum e.i.r.p. has been retained.

Consequently results can be understood as it follows:

- From nadir point (i.e off axis angle 0° from the nadir) the maximum allowable e.i.r.p. is approximately 4.2 dBW/10 MHz.
- From 43° from the nadir point the maximum e.i.r.p. is 6.7 dBW/10 MHz.
- At the edge of cell (i.e off axis angle 60° from the nadir) the maximum e.i.r.p. is approximately 5.2 dBW/10 MHz. This e.i;r.p. corresponds also to the maximum level for HAPS platform towards a gateway station located at the periphery of the UAC and where the elevation angle of the gateway station θ=30°.

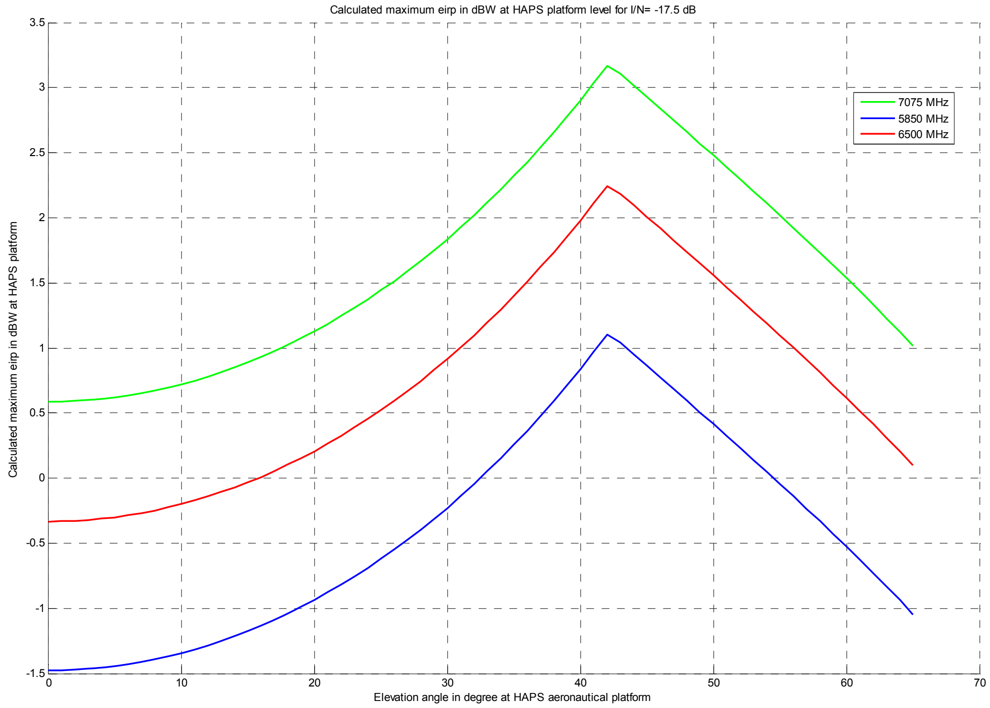


Figure 22: calculated maximum e.i.r.p. in dBW (10 MHz bandwidth) at HAPS platform for 5850 MHz, 6500 MHz and 7075 MHz

Figure **22** shows the maximum e.i.r.p. at HAPS airborne antenna output to satisfy a FWS nominal long-term interference of -147.5 dBW/10 MHz (receiver thermal noise of -130 dBW + I/N of -17.5 dB) at receiver antenna input of a FWS P-P.

It is supposed that FWS P-P may be deployed anywhere in an UAC, from the centre towards the edge of the cell and corresponding to an off-axis angle at the HAPS platform varying from 0° to 60°.

Figure **22** points out three different curves corresponding respectively to frequencies 5850 MHz, 6500 MHz, and 7075 MHz. For the need of the sharing study only the medium value of 6500 MHz (red curve) and corresponding maximum e.i.r.p. has been retained.

Consequently results can be understood as it follows:

- From nadir point (i.e off axis angle 0° from the nadir) the maximum allowable e.i.r.p. is approximately -0.5 dBW.
- At 43° from the nadir point the maximum e.i.r.p. is 2.1 dBW.
- At the edge of cell (i.e off axis angle 60° from the nadir) the maximum *e.i.r.p.* is approximately 0.5 dBW. This e.i.r.p. corresponds also to the maximum level for HAPS platform towards a gateway station located at the periphery of the UAC and where the elevation angle of the gateway station θ=30°.

These three values can be considered as the maximum e.i.r.p. for the HAPS platform with a footprint corresponding to an UAC.

5.1.2 Interference from HAPS (ground station) (uplink) into conventional FWS

HAPS Gateway station (uplink) vs FWS P-P in UAC	**θ=30° - Rain**	**θ=30° - Clear sky**
	Value	**Value**
Frequency (MHz)	6500	6500
Minimum separation distance HPAS gateway station - FSW P-P (km)	d	d
Emitted power (dBW)	-19	-19
Bandwidth MHz	11	11
Tx antenna gain (dBi)	47	47
Hardware implementation loss (dB)	-4,1	-4,1
Power control gain (dB)	8	0
HAPS Side lobe attenuation (Res.221 ref antenna pattern) (dB)	-60	-60
E.i.r.p. (dBW)	-28,5	-36,5
FWS receiver antenna gain (dBi)	43	43
FWS Side lobe attenuation (UIT-R F.1245) (dB)	-45	-45
FWS cable loss (dB)	-3	-3
FWS nominal long term interference criteria (dBW/10 MHz) (I/N=-13 dB)	-143	-143
Required attenuation at minimum distance (dB)	-109,49	-101,49
Minimum required distance (km)	**1,09**	**0,44**
FWS nominal long term interference criteria (dBW/10 MHz) (I/N=-17.5 dB)	-147.5	-147.5
Required attenuation at minimum distance (dB)	-114	-106
Minimum required distance (km)	**1.85**	**0.73**

Table 12: Calculation of the minimum required distance (km) in UAC

Free space loss attenuation model and a flat terrain have been considered in the calculation. The modeling has been performed for both rainy and clear sky conditions. In case of rain 8 dB are added in the link budget corresponding to the maximum value of power control gain for HAPS gateway link. In clear sky condition this value equals to 0 dB.

5.2 HAPS vs FSS

5.2.1 Interference from HAPS (airborne and ground station) into to non-Plan GSO fixed-satellite service systems

Following equation from Section 4.2.1 the maximum e.i.r.p. levels to protect geostationary satellite receivers (non FSS Plan of Appendix 30B RR) are derived and summarised in Table 13.

	Global beam	**Hemispheric beam**	**Semi-hemispheric beam**	**Regional beam**
$epfd_{\uparrow,\ aggregate}$ (dBW/(m².4 kHz))	-163.8	-167.8	-172.8	-177.8
d (km)	38 000	38 000	38 000	38 000
$\sum_{i=1}^{N_{HAPS}} e.i.r.p.(\theta_i)$ (dBW/4 kHz)	-1.2	-5.2	-10.2	-15.2
Maximum single-entry e.i.r.p. levels (dBW/4 kHz) (see Note)	-1.2 – 10log(N_{HAPS})	-5.2 – 10log(N_{HAPS})	-10.2 – 10log(N_{HAPS})	-15.2 – 10log(N_{HAPS})

Table 13: Derivation of maximum e.i.r.p. levels to protect geostationary FSS receivers

Note : N_{HAPS} is the number of HAPS system in visibility of the geostationary satellite multiplied by the number of simultaneously transmitting stations (either on the ground or on the platforms) per system.

In order to be able to derive accurate maximum e.i.r.p. levels able to protect geostationary satellite receivers, the knowledge of the expected deployment numbers of HAPS systems is necessary.

Taking into account that some geostationary satellites are operated in a slightly inclined orbit in order to optimise the lifetime of the satellite and noting the past practice to take such operational practice into account when implementing regulatory provisions to protect the current and future use of the geostationary arc, it is proposed that the previous maximum e.i.r.p. levels should be met in the direction of an area of the sky lying between ± 5° of the geostationary arc.

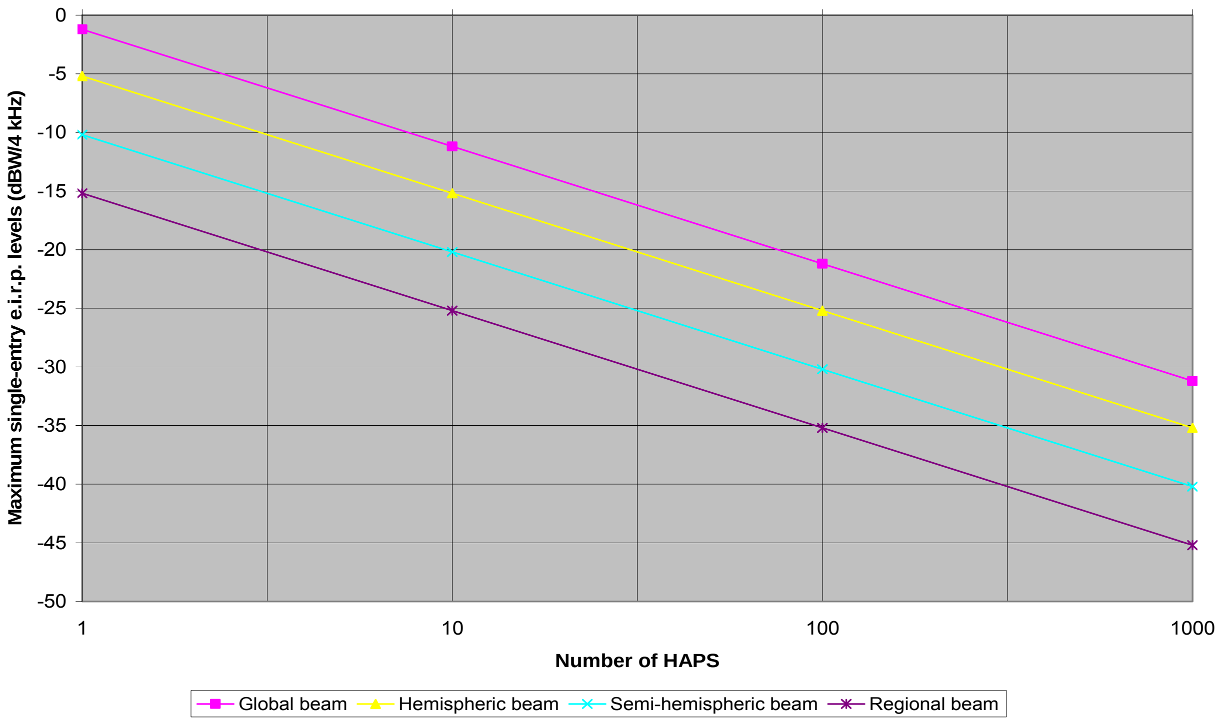


Figure 23: Max. e.i.r.p. levels of HAPS (airborne or ground) into geostationary arc depends on number of HAPS visible from specific orbital location

5.2.2 Interference from HAPS (airborne and ground station) into FSS Appendix 30B RR allotments

5.2.2.1 Scenario 1. Interference from HAPS gateway (ground) station into FSS network satellite receiver

Item	RUS00001	RUS00003	RUSLA201	XXX00001	HAPS	
HAPS Gateway station (GS) Tx Power, dBW					-19	
HAPS Gateway station Tx Antenna Gain, dBi					47	
H/W loss, dB					4.1	
Bandwidth, MHz					11	
HAPS gateway station e.i.r.p. density (dB(W/Hz))					-46.5	
Earth station FSS e.i.r.p. density (dB(W/Hz))	-7.2	-6.7	-1.4	-9.6		
Service area for FSS allotment, dB	-3	-3	-3	-3	0	
Slant distance, km	38 284	38 724	38 749	35 786 / 41 670	RUS00001	38284
					RUS00003	38724
					RUSLA201	38749
					XXX00001	35 786 / 41670
Free space loss, dB	200.9	201.0	201.0	200.3 / 201.6	RUS00001	200.9
					RUS00003	201.0
					RUSLA201	201.0
					XXX00001	200.3 / 201.6
e.i.r.p. density at FSS Rx antenna, dB(W/Hz)	-211.1	-210.7	-205.4	-212.9 / -214.2	RUS00001	-247.4
					RUS00003	-247.5
					RUSLA201	-247.5
					XXX00001	-246.8/-248.1
Received C/I, dB	36.3	36.8	42.1	33.9		
Required single entry C/I, dB	30					
Margin, dB	6.3	6.8	12.1	3.9		

Table 14: Scenario 1 calculation for FSS Plan allotments

Base on this calculation it can be concluded that there is low probability of interference from single HAPS "uplink" into FSS Plan Appendix 30B allotments. However the small value of margin, when single entry case of HAPS gateway station uplink impact to FSS Plan Appendix 30B RR allotments is considered, gives opportunity to suppose, that there will be interference from HAPS gateway links into FSS Plan allotments Appendix 30B RR when aggregate case is considered.

5.2.2.2 Sub-scenario 2a. Interference from HAPS platform station (back-lobe) into FSS network satellite receiver

The calculation in this scenario was made under free-space conditions and for back-lobe HAPS transmitter beam to main FSS satellite receiver beam geometry. The antenna radiation pattern mask used for the HAPS (airborne) payload is complies with Resolution **221 (Rev.WCR-07)** and restricted to 90°. Therefore it's assumed to use a far side-lobe level as back-lobe level.

<table>
<tr><th>Item</th><th>RUS00001</th><th>RUS00003</th><th>RUSLA201</th><th>XXX00001</th><th colspan="2">HAPS</th></tr>
<tr><td>HAPS airborne station (AS) Tx Power, dBW</td><td></td><td></td><td></td><td></td><td colspan="2">-22</td></tr>
<tr><td>HAPS airborne station Tx back-lobe antenna gain, dBi</td><td></td><td></td><td></td><td></td><td colspan="2">-43</td></tr>
<tr><td>H/W loss, dB</td><td></td><td></td><td></td><td></td><td colspan="2">4.1</td></tr>
<tr><td>Bandwidth, MHz</td><td></td><td></td><td></td><td></td><td colspan="2">11</td></tr>
<tr><td>HAPS airborne station e.i.r.p. density (dB(W/Hz)) (in back-lobe direction)</td><td></td><td></td><td></td><td></td><td colspan="2">-139.5</td></tr>
<tr><td>Earth station FSS e.i.r.p. density (dB(W/Hz))</td><td>-7.2</td><td>-6.7</td><td>-1.4</td><td>-9.6</td><td colspan="2"></td></tr>
<tr><td>Service area for FSS allotment, dB</td><td>-3</td><td>-3</td><td>-3</td><td>-3</td><td colspan="2">0</td></tr>
<tr><td rowspan="4">Slant distance, km</td><td rowspan="4">38284</td><td rowspan="4">38724</td><td rowspan="4">38749</td><td rowspan="4">35 786 / 41 670</td><td>RUS00001</td><td>38263</td></tr>
<tr><td>RUS00003</td><td>38703</td></tr>
<tr><td>RUSLA201</td><td>38728</td></tr>
<tr><td>XXX00001</td><td>35 761 / 41649</td></tr>
<tr><td rowspan="4">Free space loss, dB</td><td rowspan="4">200.9</td><td rowspan="4">201.0</td><td rowspan="4">201.0</td><td rowspan="4">200.3 / 201.6</td><td>RUS00001</td><td>200.9</td></tr>
<tr><td>RUS00003</td><td>201.0</td></tr>
<tr><td>RUSLA201</td><td>201.0</td></tr>
<tr><td>XXX00001</td><td>200.3 / 201.6</td></tr>
<tr><td rowspan="4">e.i.r.p. density at FSS Rx antenna, dB(W/Hz)</td><td rowspan="4">-211.1</td><td rowspan="4">-210.7</td><td rowspan="4">-205.4</td><td rowspan="4">-212.9 / -214.2</td><td>RUS00001</td><td>-340.4</td></tr>
<tr><td>RUS00003</td><td>-340.5</td></tr>
<tr><td>RUSLA201</td><td>-340.5</td></tr>
<tr><td>XXX00001</td><td>-339.8/-341.1</td></tr>
<tr><td>Received C/I, dB</td><td>129.3</td><td>129.8</td><td>135.1</td><td>126.9</td><td colspan="2"></td></tr>
<tr><td>Required single entry C/I, dB</td><td colspan="4">30</td><td colspan="2"></td></tr>
<tr><td>Margin, dB</td><td>99.3</td><td>99.8</td><td>105.1</td><td>96.9</td><td colspan="2"></td></tr>
</table>

Table 15: Sub-scenario 2a calculation for FSS Plan allotments

Base on this calculation it can be concluded that there is low probability of interference from single HAPS downlink into FSS Plan Appendix 30B allotments while back-lobe antenna gain is considered for HAPS airborne station. The quite big value of margin, when single entry case of HAPS gateway station downlink impact to FSS Plan Appendix 30B RR allotments is considered, gives opportunity to suppose, that there will not be interference from HAPS gateway links into FSS Plan allotments Appendix 30B RR when aggregate case is considered.

5.2.2.3 **Sub-scenario 2b. Interference from HAPS platform station (main-lobe) into FSS network satellite receiver**

The calculation in this scenario was made under free-space conditions and for main HAPS transmitter beam to main FSS satellite receiver beam geometry. A conditional allotment **XXX00001** was considered in this case only. A slant distance between HAPS (with altitude 21 – 25 km) and FSS satellite is 42 200 km (see Figure 15).

Item	XXX00001	HAPS
HAPS airborne station (AS) Tx Power, dBW		-22
HAPS airborne station Tx Antenna Gain, dBi		30
H/W loss, dB		4.1
Bandwidth, MHz		11
HAPS airborne station e.i.r.p. density (dB(W/Hz))		-66.5
Earth station FSS e.i.r.p. density (dB(W/Hz))	-9.6	
Service area for FSS allotment, dB	-3	0
Slant distance, km	41 670	42 200
Free space loss, dB	201,6	201,7
e.i.r.p. density at FSS Rx antenna, dB(W/Hz)	-214,2	-268,2
Received C/I, dB		
Required single entry C/I, dB	54	
Margin, dB	24	

Table 16: Sub-scenario 2b calculation for FSS Plan allotments

Base on this calculation it can be concluded that there is low probability of interference from HAPS downlink into FSS Plan Appendix 30B allotments when main lobe antenna gain is considered for HAPS airborne station. It needs to be mentioned that the minimum elevation angle for each test point included in the service area of FSS Plan allotments is 10° (see Item 1.3 Annex 1 to Appendix 30B RR). Therefore the main HAPS (airborne station) transmitter beam to main FSS satellite receiver beam geometry is not realistic and considered only as theoretical worst case assumption.

5.2.3 Interference from HAPS (airborne and ground station) emissions into non-geostationary FSS receiver

5.2.3.1 Scenario 1. Interference from HAPS gateway (ground) station into non-GSO FSS network satellite receiver

Item	MOLNIA	HAPS gateway station
HAPS Gateway station (GS) Tx Power, dBW		-19
HAPS Gateway station Tx Antenna Gain, dBi		47
H/W loss, dB		4.1
Bandwidth, MHz		11
HAPS airborne station e.i.r.p. density		30.4 dB(W/50 MHz)
Earth station FSS e.i.r.p. density	90 dB(W/50 MHz)	
Slant distance, km	45 380	40 000
Free space loss, dB	201.4	200.3
e.i.r.p. density at FSS Rx antenna	-111.4 (W/50 MHz)	-169.9 dB(W/50 MHz)
Max. noise power at FSS Rx antenna, dB	-117.6	
C/N, dB	6.2	
Required C/I, dB	18.4	
Received C/I, dB	58.5	
Margin, dB	40.2	

Table 17: Scenario 1 calculation for non-GSO FSS systems

Base on this calculation it can be concluded that there is low probability of interference from single HAPS uplink into non-GSO FSS space station receiver for MOLNIA-type systems. The quite big value of margin, when single entry case of HAPS gateway station uplink impact to non-GSO FSS space station receiver of MOLNIA-type systems is considered, gives opportunity to suppose, that there will not be interference from HAPS gateway links into non-GSO FSS space station receiver of MOLNIA-type systems when aggregate case is considered.

5.2.3.2 Sub-scenario 2a. Interference from HAPS platform station (back-lobe) into non-GSO FSS network satellite receiver

The calculation was made for back-lobe HAPS transmitter beam to main FSS satellite receiver beam geometry. The antenna radiation pattern mask used for the HAPS (airborne) payload is complies with Resolution **221 (Rev.WCR-07)** and restricted to 90°. Therefore it's assumed to use a far side-lobe level as back-lobe level.

Item	MOLNIA	HAPS
HAPS airborne station (AS) Tx Power, dBW		-22
HAPS airborne station Tx back-lobe antenna gain, dBi		-43
H/W loss, dB		4.1
Bandwidth, MHz		11
HAPS airborne station e.i.r.p. density		-62.5 dB(W/50 MHz)
Earth station FSS e.i.r.p. density	90 dB(W/50 MHz)	
Slant distance, km	45 380	39 887
Free space loss, dB	201.4	200.3
e.i.r.p. density at FSS Rx antenna	-111.4 dB(W/50 MHz)	-262.8 dB(W/50 MHz)
Max. noise power at FSS Rx antenna, dB	-117.6	
C/N, dB	6.2	
Required C/I, dB	18.4	
Received C/I, dB	151.4	
Margin, dB	133.0	

Table 18: Sub-scenario 2a calculation for non-GSO FSS systems

Base on this calculation it can be concluded that there is low probability interference from HAPS down link into non-GSO FSS space station receiver for MOLNIA-type systems while back-lobe antenna gain of transmitter airborne HAPS station is considered. The quite big value of margin, when single entry case of HAPS gateway station downlink impact to non-GSO FSS space station receiver of MOLNIA-type systems is considered, gives opportunity to suppose, that there will not be interference from HAPS gateway links non-GSO FSS space station receiver of MOLNIA-type systems when aggregate case is considered.

5.2.3.3 Sub-scenario 2b. Interference from HAPS platform station (main-lobe) into non-GSO FSS network satellite receiver

Item	MOLNIA	HAPS
HAPS airborne station (AS) Tx Power, dBW		-22
HAPS airborne station Tx maine-lobe antenna gain, dBi		30
H/W loss, dB		4.1
Bandwidth, MHz	50	11
HAPS airborne station e.i.r.p. density		10.4 dB(W/50 MHz)
Earth station FSS e.i.r.p.. density	90 dB(W/50 MHz)	
Slant distance, km	45 380	46 470
Free space loss, dB	201.3	201.6
e.i.r.p. density at FSS Rx antenna	-111.4 dB(W/50 MHz)	-191.2 dB(W/50 MHz)
Max. noise power at FSS Rx antenna, dB	-117.6	
C/N, dB	6.2	
Required C/I, dB	18.4	
Received C/I, dB	79.8	
Margin, dB	61.4	

Table 19: Sub-scenario 2b calculation for non-GSO FSS systems

Base on this calculation it can be concluded that there is low probability of interference from HAPS down link into non-GSO FSS space station receiver of MOLNIA-type systems while main-lobe antenna gain of transmitter airborne HAPS station is considered. The quite big value of margin, when single entry case of HAPS gateway station downlink impact to non-GSO FSS space station receiver of MOLNIA-type systems is considered, gives opportunity to suppose, that there will not be interference from HAPS gateway links non-GSO FSS space station receiver for MOLNIA-type systems when aggregate case is considered.

5.3 HAPS vs ITS

5.3.1 Interference from HAPS airborne station emissions into ITS receiver

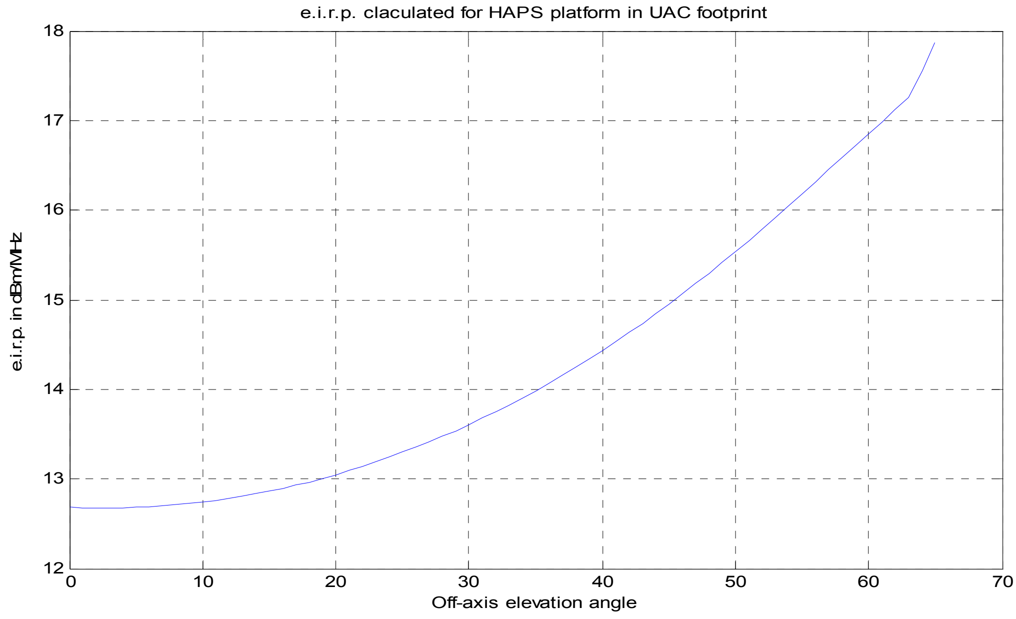


Figure 24: calculated max EIRP vs off axis angle

Figure 24 shows the maximum e.i.r.p. at HAPS platform antenna output to satisfy the allowable interfering power criterion of -106 dBm/MHz (or -136 dB/MHz) at ITS receiver antenna input.

For an UAC footprint the result is that from nadir point (i.e off axis angle 0° from the nadir) the maximum allowable e.i.r.p. varies between 12.6 dBm/MHz (or -7.4 dBW/10 MHz) to 16.8 dBm/MHz (or -3.8 dBW/10 MHz).

5.3.2 Interference from HAPS gateway station emissions into ITS receiver.

HAPS Gateway station (uplink) vs ITS OBU in UAC	UAC - Rain	UAC - clear sky
	Value	Value
Frequency (MHz)	5900	5900
Minimum separation distance (km)	d	d
Emitted power (dBW)	-19	-19
Bandwidth (MHz)	11	11
Tx antenna gain (dBi)	47	47
Hardware implementation loss (dB)	-4,1	-4,1
Power control gain (dB)	8	0
HAPS Side lobe attenuation (dB) (Res.221 ref antenna pattern)	-60	-60
e.i.r.p. (dBW/MHz)	-38,1	-46,1
e.i.r.p. (dBm/MHz)	-8,1	-16,1
ITS receiver antenna gain (dBi) (Rec ITU-R F.1336)	8	8
ITS Allowable Interfering Power at receiver antenna input (dBm/MHz)	-106	-106
Required attenuation at minimum distance (dB)	-105,9	-97,9
Minimum required separation distance (km)	**0,79**	**0,32**

Table 20: Calculation of the minimum required distance in UAC

Free space loss attenuation model and flat Earth are considered in the calculation.

5.4 HAPS vs EESS

5.4.1 Result of static simulation

Following the channel plan submitted in Section 2.3 there are 6 carriers for each of the two 80 MHz channels.

In Scenario 1, where there is overlapping only between HAPS gateway links (uplink) and EESS (passive), a total transmitter power Pt of a single HAPS gateway link is -15.3 dBW in the reference 200 MHz (-19 dBW/carrier – 4.1 dB of losses: -23.1 dBW/carrier + 10*Log(6 carriers)).

The transmitter gain Gt_{HAPS} is 47 dBi.

With a central frequency of 6600 MHz and a slant distance between satellite (orbit height around 700 km with a tilt antenna angle of around 47 degrees) and HAPS gateway station of ~1000 km we obtain a space loss Ls of -168.85 dB.

The receiver gain Gr_{EESS} is 38.8 dBi (Sensor B1 in Table 10).

The worst case situation is explained as follows. The power reaching the EESS sensor with a main beam to main beam coupling results therefore in -15.3 + 47 – 168.85 + 38.8 = -98.35 dBW. This constitutes a deficit of 67.65 dB with respect to the sensor protection level of -166 dBW for a bandwidth of 200 MHz (Recommendation ITU-R RS.1029-2). Furthermore, it is to be noted that this deficit would occur for a single gateway uplink and doesn't take into account any aggregate effect from multiple gateways.

However, as it is a worst case situation main beam to main, it is probably unlikely that such a situation will occur. Therefore, it is necessary to investigate the statistics of sidelobe to main lobe interference, and also the sidelobe to sidelobe coupling for a single gateway and also for an aggregation of multiple gateways and HAPS networks.

In Scenario 2, where there is overlapping only between HAPS gateway links (downlink) and EESS (passive), a total transmitter power Pt of a single HAPS gateway link is -18.3 dBW in the reference 200 MHz (-22 dBW/carrier – 4.1 dB of losses: -26.1 dBW/carrier + 10*Log(6 carriers)).

The transmitter maximum gain in the main lobe Gt_{HAPS} is 30 dBi. Following the equations in Annex 1 the far side-lobe level of airborne antenna is -43 dBi.

In this Scenario the power reaching the EESS sensor with a far side-lobe to main beam coupling results therefore in -18.3 + (-43) – 168.85 + 38.8 + 10*Log(5) - it is a max number of gateway stations per HAPS = -184.4 dBW. It is below the sensor protection level of -166 dBW for a bandwidth of 200 MHz (Recommendation ITU-R RS.1029-2). Therefore it may be concluded that there is no interference from single HAPS gateway links (downlink) to EESS (passive) even thought the main EESS sensor antenna beam. However, the impact from HAPS (downlink) emissions reflected from the ocean surface to passive sensors in the EESS has not been assessed in this Report.

Taking into account that in Scenario 1 there is a deficit of 67.65 dB with respect to the sensor protection level of -166 dBW for a bandwidth of 200 MHz (Recommendation ITU-R RS.1029-2) there is no need to consider Scenario 3.

5.4.2 Result of dynamic simulation

Following the results submitted in Section 5.4.1 above the dynamic simulations were conducted for the HAPS uplink case only. This results are valid for the HAPS gateway antenna pattern having a performance in Figure 3 corresponding to Ln = -25 dB from Resolution **221(Rev. WRC-07)**. The passive sensor which is simulated is AMSR-E (sensor B1 of Recommendation ITU-R RS.1861 in Table 10) since it is a current flying sensor. The average Recommendation ITU-R RS.1813 antenna pattern has been assumed for the sensor. 10 HAPS platforms have been assumed operating in an area of 10,000,000 km^2, corresponding to the reference area specified in Recommendation ITU-R RS.1029. Each HAPS platform was assumed to be served by 5 gateway stations with 6 channels of 11 MHz each, i.e. 300 gateway channels in total. Details are given in Table 21 below.

Reference area (km^2)	10,000,000
Number of HAPS platforms in reference area	10
Gateway stations per platform	5
Number of gateway channels	6
Bandwidth of gateway channels (MHz)	11
Power of gateway channels including losses (dBW/11 MHz)	-23.1
Antenna gain (dBi)	47
Elevation range for gateway stations (deg.)	30 – 90

Table 21: Assumptions for interference assessment from HAPS gateway links to EESS(passive)

Figure **25** shows the results for 2 scenarios. The first is based on the assumption that all 300 gateway links operate inside the reference area. Recommendation ITU-R RS.1029 protection criteria are exceeded by around 13-20 dB. Moreover, it is to be noted that at 0.001 %, a level of -130 dBW/200 MHz, which may cause damage for the sensor since the input level, is largely above the interference threshold.

The second scenario is based on observations over water with no gateway stations inside the reference area but only some adjacent to it. In this case the protection criteria could be met by around 8-10 dB however HAPS gateway stations can not be located close to the seacoast or under islands and archipelagic waters. It seems unrealistic scenario therefore sharing between HAPS (uplink) with EESS (passive) in the frequency band 6425-7075 MHz is unlikely to be feasible.

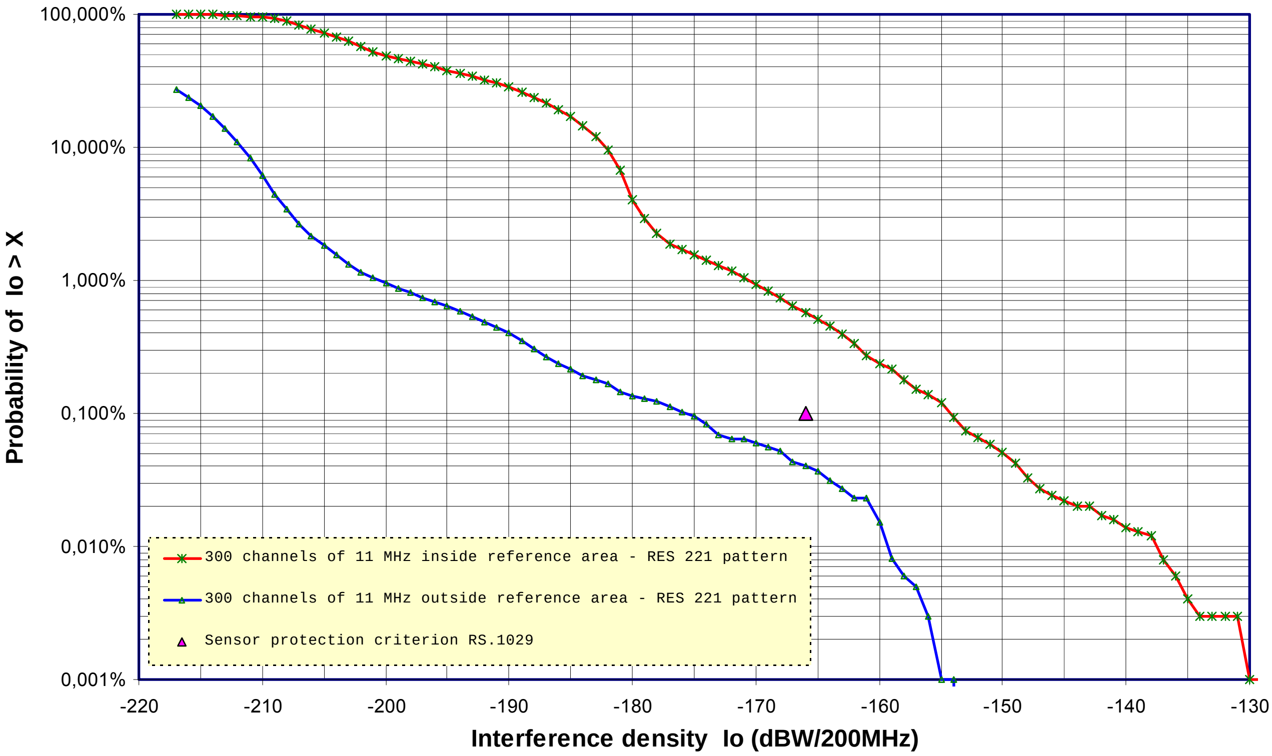


Figure 25: Dynamic simulation for a gateway within the EESS observation zone and transmitting within a channel of 11 MHz

5.5 HAPS vs RAS

5.5.1 Calculation for HAPS (uplink)

In Scenario 1, where there is overlapping between HAPS gateway links (uplink) and RAS a total transmitter spectral power Pt of a single HAPS gateway link carrier is -85.5 dBW/Hz (-19 dBW/carrier – 4.1 dB of losses + 8dB rain condition - 10*Log(11 MHz)).

The transmitter gain Gt_{HAPS} is 47 dBi that correspondence to -26 dBi for minimum elevation angle 30 deg for gateway stations. The receiver gain Gr_{RAS} is 0 dBi (Recommendation ITU-R RA.769). We assume 0 dB rain attenuation, as RA thresholds are defined on a 2% probability level. Therefore the effective e.i.r.p. of the base station is 4.5 dBm/MHz or -85.5 dBW/Hz.

The effective sidelobe transmitted spdf is given by $S_{tx} := \frac{P_{EIRP}\left(P_{out}, G_{tx}, G_{off}\right) \cdot 4 \cdot \pi \cdot \nu_o^2}{c^2}$ which yields a value of -73.6 $dBWm^{-2}Hz^{-1}$. According to Recommendation ITU-R RA.769 the applicable interference threshold for 6.6 GHz spectroscopy observations is -230 $dBWm^{-2}Hz^{-1}$. Hence the distance between a HAPS ground station and radio astronomical antenna must provide for a path loss of at least 156 dB.

The operating height of a HAPS base station is presumed to be 2 m. In that case, the optical horizon for a link between HAPS base stations and a 50m antenna will be 30 km. Figure 26 shows the result of a path loss estimate according to ITU-R P.452 (including atmospheric absorption). The blue dotted line is the line of sight path loss and the green dotted line the loss caused by troposcatter. The protection distance falls in the region dominated by diffraction over the spherical earth. The red line is the path loss required for the protection of the radio astronomical site. Numerical calculation of the minimum distance where the requirement is met yields a distance of $\mathbf{d_{prot}}$ **= 31.6 km** for a single ground station on flat terrain. Topography and ground clutter may provide further attenuation, but in order to account for it, one has to consider the different local environment around individual radio observatories.

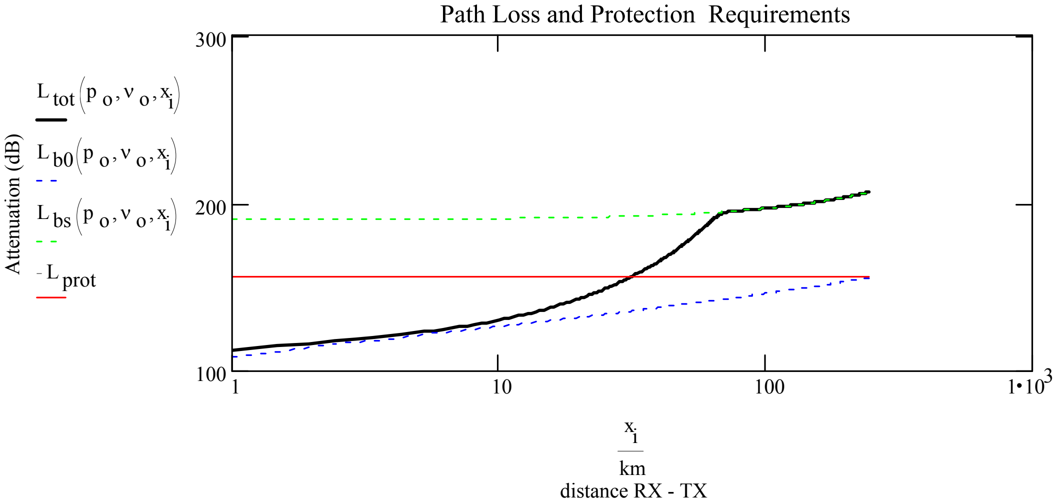


Figure 26: The path loss and protection requirements for the HAPS (uplink)

Aggregation of Ground Stations

It is assumed that the parameters for the single interferer given above also describe the average HAPS ground station. Using the ring integration method it is derived the radii of exclusion zones for HAPS ground stations around a radio astronomical observatory as shown in Figure 27.

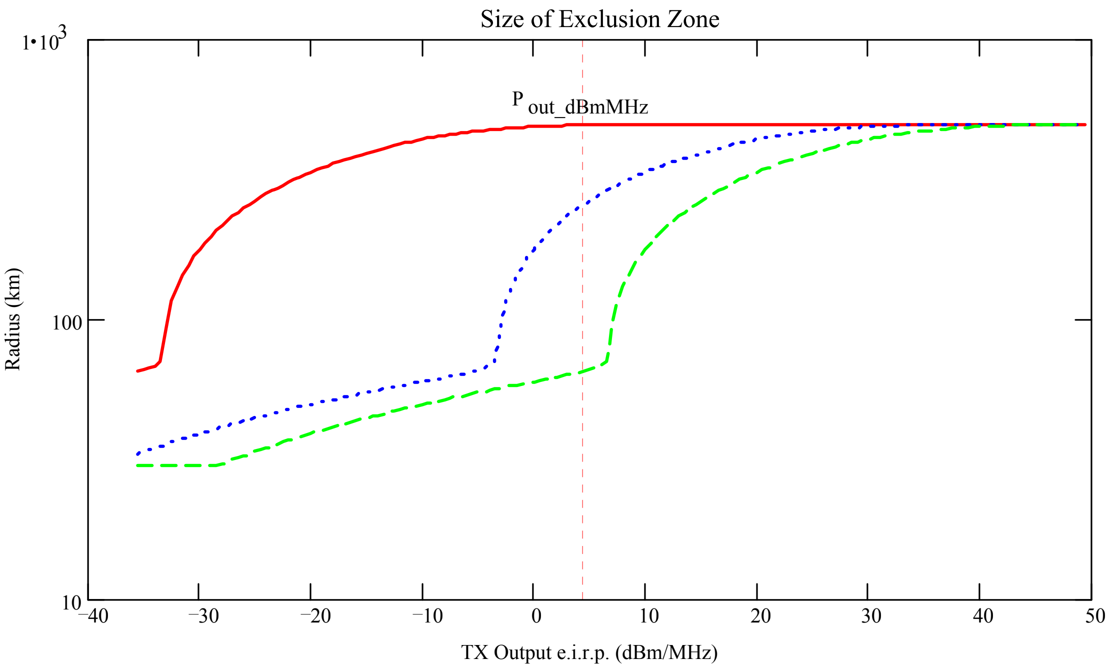


Figure 27: The radii of exclusion zones for HAPS ground stations around a radio astronomical observatory

The dashed red vertical line corresponds to the nominal e.i.r.p. of a single HAPS ground station. The red line shows the size of the exclusion zone as a function of e.i.r.p. for a density of 1 ground station per km^2. The density of ground stations is not supposed to exceed 10^{-3} km^{-2}. Therefore the blue dashed line shows the size of the exclusion zone for a density of 10^{-3} km^{-2}, and the green dashed line for $10^{-4} km^{-2}$. For the nominal ground station e.i.r.p. of 4.5 dBm/MHz one finds that the exclusion zone has to be $\mathbf{d_{prot}}$ **= 258 km** for the maximum projected density of 10^{-3} km^{-2} of ground stations, and $\mathbf{d_{prot}}$ **= 66 km** for the lower density value of 10^{-4} km^{-2}. The graph also illustrates, that the protection radius is very insensitive to parameter variation in the spherical earth diffraction regime. A reduction in power by 20 dB or different antenna patterns of the ground station does not have a significant effect here.

5.5.2 Calculation for HAPS (downlink)

In Scenario 2, there is overlapping between HAPS gateway links (downlink) and RAS. Single HAPS may operate with up to 5 ground based gateway stations. Therefore a total transmitter spectral power Pt of a single HAPS airborne station is -81.5 dBW/Hz (-22 dBW/carrier – 4.1 dB of losses + 8dB power control -10*Log(11 MHz) + 10*Log(5 stations)).

The transmitter gain Gt HAPS is +30 dBi. The HAPS airborne station communicates with ground gateway stations with minimum elevation angle 30 deg. It is assumed that 9 dB rain attenuation. Therefore the effective e.i.r.p. of the base station is 0.5 dBm/MHz or -90.5 dBW/Hz.

The effective sidelobe transmitted spdf is given by $S_{tx} := \frac{P_{EIRP}\left(P_{out}, G_{tx}, G_{off}\right) \cdot 4 \cdot \pi \cdot \nu_o^2}{c^2}$ which yields -20.6 $dBWm^{-2}Hz^{-1}$. According to Recommendation ITU-R RA.769 the applicable interference threshold for 6.6 GHz spectroscopy observations is -230 $dBWm^{-2}Hz^{-1}$. Hence the distance between a HAPS base station and radio astronomical antenna must provide for a path loss of at least 209 dB.

The minimum altitude of a HAPS base station is presumed to be 20 km. In that case, the optical horizon for a link between HAPS base stations and a 50m antenna will be 529 km.

No topographical attenuation is expected for high altitude airborne transmissions.

The Figure 28 below shows the result of a path loss estimate according to Recommendation ITU-R P.452 (including atmospheric absorption). The blue dotted line is the line of sight path loss and the green dotted line the loss caused by troposcatter. The short transition region is dominated by diffraction over the spherical earth. The red line is the path loss required for the protection of the radio astronomical site. Numerical calculation of the minimum distance where the requirement is met yields a distance of $\mathbf{d_{prot} = 679}$ **km.**

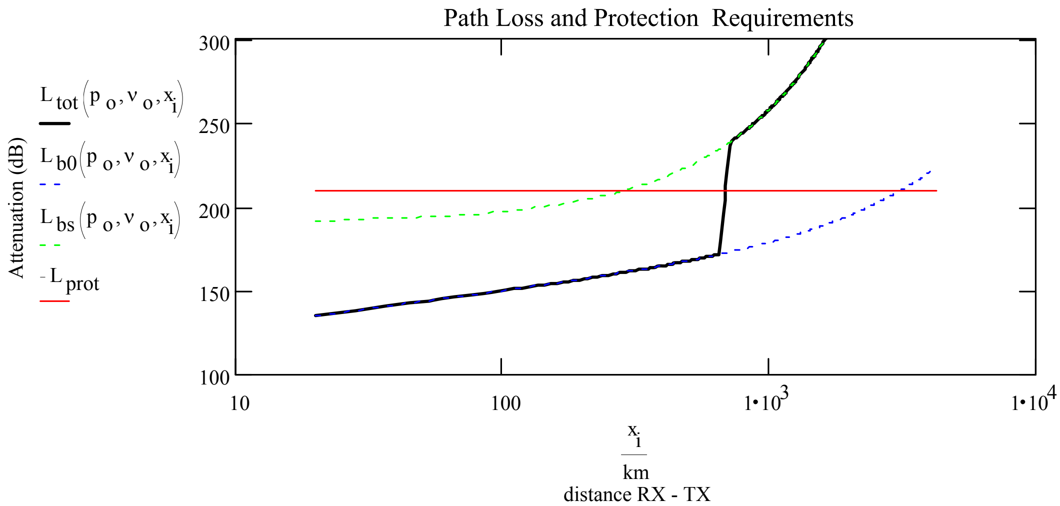


Figure 28: The path loss and protection requirements

All other cases (direct reception, near side lobe emission by the radio telescope) require even greater separation distances. From Figure 28, one can discern that the protection distance corresponds to the steep diffraction transition regime. A signal attenuation of more than 70 dB is required to reduce the range to the line of sight horizon of 529 km. Taking into account the cumulative effect of a greater number of HAPS airborne stations or the effect antenna gain variation with viewing angle of RAS it may concluded that sharing between HAPS (downlink) and RAS is not feasible in Europe.

6 ANALYSIS OF THE STUDIES

6.1 HAPS vs FWS

6.1.1 HAPS airborne platform (downlink) vs FWS

From results presented in Figure 21 a e.i.r.p. mask could be derived for the protection of point-to-point fixed service stations operating in co-frequency at 6500 MHz from interference (for a I/N of -13 dB) that may occur from the HAPS platform station:

- for 0° ≤ θ ≤ 20°, θ is the off-axis angle from the nadir e.i.r.p. mask should be comply with a range between 4.15 dBW/10 MHz and 4.75 dBW/10 MHz;
- for 20° < θ ≤ 43°, θ is the off-axis angle from the nadir e.i.r.p. mask should be comply with a range between 4.75 dBW/10 MHz and 6.7 dBW/10 MHz;
- for 43° < θ ≤ 60°, θ is the off-axis angle from the nadir e.i.r.p. mask should be comply with a range between 6.7 dBW/10 MHz and 5.1 dBW/10 MHz.

From results presented in Figure **22** a e.i.r.p. mask could be derived for the protection of point-to-point fixed service stations operating in co-frequency at 6500 MHz (red curve) from interference (for a I/N of -17.5 dB) that may occur from the HAPS platform station (downlink):

- for 0° ≤ θ ≤ 20°, θ is the off-axis angle from the nadir e.i.r.p. mask should be comply with a range between -0.5 dBW/10 MHz and 0 dBW/10 MHz;
- for 20° < θ ≤ 43°, θ is the off-axis angle from the nadir e.i.r.p. mask should be comply with a range between 0 dBW/10 MHz and 2.1 dBW/10 MHz;
- for 43° < θ ≤ 60°, θ is the off-axis angle from the nadir e.i.r.p. mask should be comply with a range between 2.1 dBW/10 MHz and 0.5 dBW/10 MHz.

These masks relate to the e.i.r.p. that would be obtained assuming free-space loss. It is assumed that the maximum angle of the HAPS airborne antenna deviation from the nadir should be limited to 60 degrees corresponding to the UAC of the HAPS.

6.1.2 HAPS gateway link (uplink) vs FWS

Results in Table 12 show the minimum required separation distance for the protection of point-to-point fixed service stations operating in co-frequency at 6500 MHz from interference that may occur from a HAPS gateway station. In clear sky conditions:

- the minimum separation distance is 500 m whereas in rainy conditions this minimum distance increases to 1100 m (for a I/N of -13 dB);
- the minimum separation distance is 730 m whereas in rainy conditions this minimum distance increases to 1850 m (for a I/N of -17.5 dB).

6.2 HAPS vs FSS

6.2.1 Interference from HAPS (airborne and ground station) into geostationary FSS (non Plan FSS)

	Global beam	Hemispheric beam	Semi-hemispheric beam	Regional beam
Maximum single-entry e.i.r.p. levels (dBW/4 kHz) (see Note)	$-1.2 - 10\log(N_{HAPS})$	$-5.2 - 10\log(N_{HAPS})$	$-10.2 - 10\log(N_{HAPS})$	$-15.2 - 10\log(N_{HAPS})$

Table 22: Results of studies for FSS (non-Plan GSO case)

Note : N_{HAPS} is the number of HAPS system in visibility of the geostationary satellite multiplied by the number of simultaneously transmitting stations (either on the ground or on the platforms) per system.

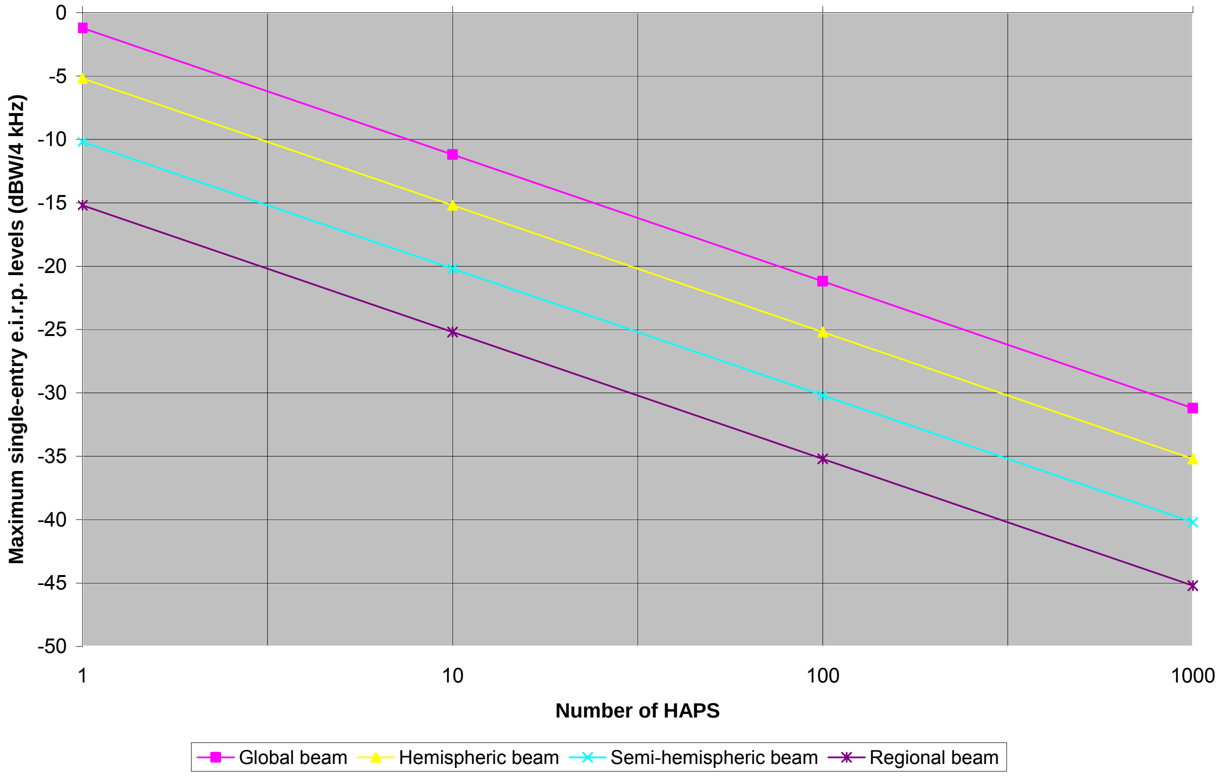


Figure 29: Max. e.i.r.p. level of HAPS (airborne or ground) into geostationary arc depends on number of HAPS visible from specific orbital location

6.2.2 Interference from HAPS (airborne and ground station) into geostationary Plan FSS

It may be concluded that there is low probability of interference from single HAPS “uplink” into FSS Plan Appendix 30B allotments. However the small value of margin (3.9 dB), when single entry case of HAPS gateway station uplink impact to FSS Plan Appendix 30B RR allotments is considered, gives opportunity to suppose, that there will be interference from HAPS gateway links into FSS Plan allotments Appendix 30B RR when aggregate case is considered. Even one HAPS airbone station may operate with 5 ground gateway stations simultaneously therefore the identification of HAPS “uplink” channels is not recommended in the frequency band 6725-7025 MHz where there is FSS Plan allotments Appendix 30B RR.

HAPS downlink may consider in the frequency band 6725-7025 MHz because there is low probability of interference from HAPS downlink into FSS Plan Appendix 30B allotments even for aggregate interference case. However it should be noted that *Existing systems* of Appendix 30B RR, operating in the frequency band 6725-7025 MHz in accordance with Resolution **148 (Rev.WRC-07)**, and *Additional systems* are out of this study. Therefore the study results may not be applicable for these systems that are also a subject of the provisions of the FSS Plan Appendix 30B RR.

6.2.3 Interference from HAPS (airborne and ground station) into non-geostationary FSS

There is low probability of interference from single HAPS uplink or downlink into non-GSO FSS space station receiver for MOLNIA-type systems. The quite big value of margin, when single entry case of HAPS uplink or downlink impact to non-GSO FSS space station receiver for MOLNIA-type systems is considered, gives opportunity to suppose, that there will not be interference from HAPS gateway links to non-GSO FSS space station receiver of MOLNIA-type systems when aggregate case is considered.

6.3 HAPS vs ITS

6.3.1 HAPS airborne platform (downlink) vs ITS

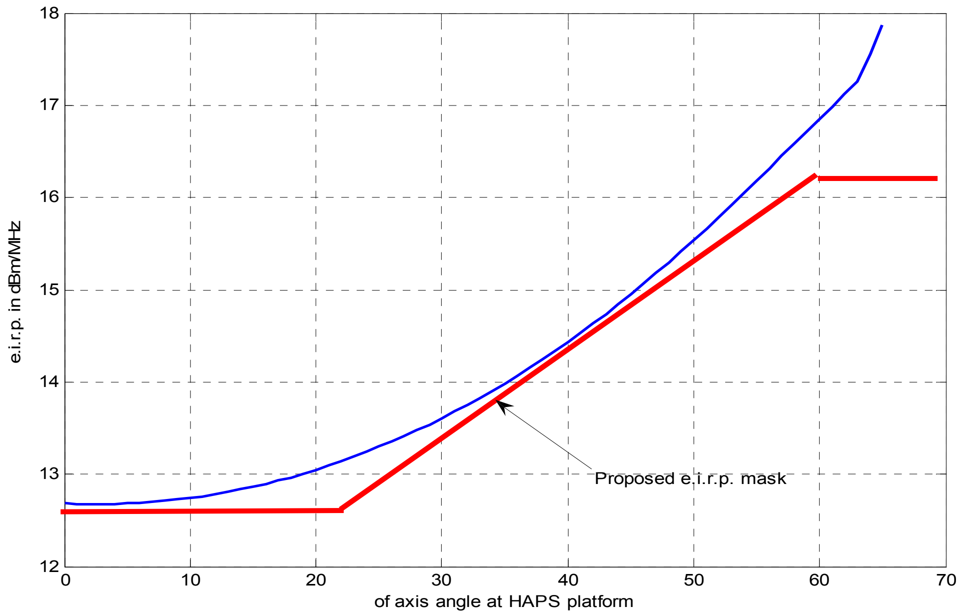


Figure 30: derived preliminary e.i.r.p. mask for HAPS platform

From results calculated in Figure 24 and presented in Figure 30 above show a derived preliminary e.i.r.p. mask that could be proposed for the protection of ITS OBU stations operating in co-frequency at 5900 MHz from interference that may occur from the HAPS platform station:

e.i.r.p. = 12.6 dBm/MHz (or -7.4 dBW/10 MHz) for $0° \leq \theta \leq 22°$,

e.i.r.p. linearly increases from 12.6 dBm/MHz (or -7.4 dBW/10 MHz) to 16.2 dBm/MHz (or -3.8 dBW/10 MHz) for $22° < \theta \leq 60°$.

θ is the off-axis angle from the nadir.

This mask relates to the e.i.r.p. that would be obtained assuming free-space loss. It is assumed that the maximum angle of the HAPS airborne antenna deviation from the nadir should be limited to 60 degrees corresponding to the UAC of the HAPS.

6.3.2 HAPS gateway link (uplink) vs ITS

Results in Table 20 show the minimum required separation distance for the protection of ITS OBU mobile service stations operating in co-frequency at 5900 MHz from interference that may occur from a HAPS gateway station.

In clear sky conditions the minimum separation distance is 320 m whereas in rainy conditions this minimum distance is equal to 800 m.

6.4 HAPS vs EESS

Based on the result of static and dynamic simulations it may be concluded that in the frequency band 6425-7075 MHz:

- sharing between HAPS (uplink) with EESS (passive) is unlikely to be feasible due to exceed of Recommendation ITU-R RS.1029 protection criteria;
- sharing between HAPS (downlink) with EESS (passive) is feasible without any specific operational limitations for HAPS.

6.5 HAPS vs RAS

Based on the result of study it may be concluded that in the frequency band 6650-6675.2 MHz:

- sharing between HAPS (uplink) with RAS is feasible however in order to protect RAS from HAPS (uplink) it requires separation distance around 31.6 km for a single ground station on flat terrain;

- sharing between HAPS (downlink) with RAS is not feasible in collocated geographical areas.

7 CONCLUSIONS

In response to Resolution **734 (Rev.WRC-07)** calling for sharing studies for spectrum identification of HAPS (High Altitude Platform Station) gateway links in the range from 5850 to 7075 MHz, the CEPT conducted compatibility studies between HAPS system and different other services.

Services which have been considered are the following:

1) Fixed Service

2) Fixed Satellite Service (geostationary (Plan Appendix 30B RR and non-Plan) and non-geostationary)

3) Mobile Service (Intelligent Transport Systems)

4) Earth Exploration-Satellite Service

5) Radio Astronomy Service.

The following table shows the conditions under which sharing would be feasible:

Services and applications	HAPS as interferer system vs other Services
FS	**Aeronautical platform (downlink):** In order to meet the FWS nominal long term interference criterion of -147.5 dBW/10 MHz taking into account apportionment considerations of the allowable interference into the FS , the maximum e.i.r.p. at HAPS airborne antenna output should be: • for $0° \leq \theta \leq 20°$, θ is the off-axis angle from the nadir e.i.r.p. mask should be comply with a range between -0.5 dBW/10 MHz and 0 dBW/10 MHz; • for $20° < \theta \leq 43°$, θ is the off-axis angle from the nadir e.i.r.p. mask should be comply with a range between 0 dBW/10 MHz and 2.1 dBW/10 MHz; • for $43° < \theta \leq 60°$, θ is the off-axis angle from the nadir e.i.r.p. mask should be comply with a range between 2.1 dBW/10 MHz and 0.5 dBW/10 MHz. This mask relates to the e.i.r.p. that would be obtained assuming free-space loss. In order to meet the FWS nominal long term interference criterion of −147.5 dBW/10 MHz, an e.i.r.p. limit of −0.5 dBW/10 MHz for HAPS (downlink) is proposed which is invariant to an off-axis angle up to 60° from the nadir, which corresponds to a minimum elevation angle for the gateway station of 30°. **Gateway link (uplink) :** Compatibility is achieved if minimum separation distances are defined between gateway station and FWS systems. • in clear sky conditions the minimum separation distance is 730 m whereas; • in rainy conditions this minimum distance increases to 1850 m. It is assumed that a minimum elevation angle for the HAPS gateway station is limited by 30°.

FSS	To protect the geostationary non-Plan FSS networks the maximum e.i.r.p. at HAPS (airborne or ground) depends on the number of the HAPS within service area of the FSS satellite. Specific values are submitted in separate Table 2 below. The identification of HAPS "uplink" channels is not recommended in the frequency band 6725-7025 MHz where there is FSS Plan allotments Appendix 30B RR. However HAPS downlink may be considered in the frequency band 6725-7025 MHz because there is low probability of interference from HAPS downlink into FSS Plan Appendix 30B allotments even for aggregate interference case. At the same time it should be noted that *Existing systems* of Appendix 30B RR, operating in the frequency band 6725-7025 MHz in accordance with Resolution **148 (Rev.WRC-07)**, and *Additional systems* are out of this study. Therefore the study results may not be applicable for these systems that are also a subject of the provisions of the FSS Plan Appendix 30B RR. There is low probability of interference from single HAPS uplink or downlink into non-GSO FSS space station receiver for MOLNIA-type systems. The quite big value of margin, when single entry case of HAPS uplink or downlink impact to non-GSO FSS space station receiver for MOLNIA-type systems is considered, gives opportunity to suppose, that there will not be interference from HAPS gateway links to non-GSO FSS space station receiver of MOLNIA-type systems when aggregate case is considered.
MS	**Aeronautical platform (downlink) :** In order to meet the ITS nominal long term interference criterion of -106 dBm/MHz, the maximum e.i.r.p. at HAPS airborne antenna output should be : • e.i.r.p. = 12.6 dBm/MHz (or -7.4 dBW/10 MHz) for $0° \leq \theta \leq 22°$; • e.i.r.p. linearly increases from 12.6 dBm/MHz (or -7.4 dBW/10 MHz) to 16.2 dBm/MHz (or -3.8 dBW/10 MHz) for $22° < \theta \leq 60°$. θ is the off-axis angle from the nadir. This mask relates to the e.i.r.p. that would be obtained assuming free-space loss. It is assumed that the maximum angle of the HAPS airborne antenna deviation from the nadir should be limited to 60 degrees corresponding to the UAC of the HAPS. **Gateway link (uplink) :** Compatibility is achieved if minimum separation distances are defined between gateway station and ITS systems. • in clear sky conditions the minimum separation distance is 320 m; • in rainy conditions this minimum distance is equal to 800 m. It is assumed that a minimum elevation angle for the HAPS gateway station is limited by 30°.
EESS	Sharing between HAPS (uplink) with EESS (passive) is unlikely to be feasible in the frequency band 6425-7075 MHz due to exceed of Recommendation ITU-R RS.1029 protection criteria. Sharing between HAPS (downlink) with EESS (passive) is feasible without any specific operational limitations for HAPS. However, the impact from HAPS (downlink) emissions reflected from the ocean surface to passive sensors in the EESS has not been assessed in this Report.
RAS	In the frequency band 6650-6675.2 MHz: - sharing between HAPS (uplink) with RAS is feasible however in order to protect RAS from HAPS (uplink) it requires separation distance around 31.6 km for a single ground station on flat terrain; - sharing between HAPS (downlink) with RAS is not feasible in collocated geographical areas.

Table 23: Summary of sharing conditions where HAPS interferers with other Services and applications

	Global beam	Hemispheric beam	Semi-hemispheric beam	Regional beam
Maximum single-entry e.i.r.p. levels (dBW/4 kHz) (see Note)	$-1.2 - 10\log(N_{HAPS})$	$-5.2 - 10\log(N_{HAPS})$	$-10.2 - 10\log(N_{HAPS})$	$-15.2 - 10\log(N_{HAPS})$

Table 24: Maximum e.i.r.p. at the HAPS as a function of number of the HAPS to protect geostationary non-Plan FSS networks

Note : N_{HAPS} is the number of HAPS system in visibility of the geostationary satellite multiplied by the number of simultaneously transmitting stations (either on the ground or on the platforms) per system.

ANNEX 1: HAPS ANTENNA PATTERNS

A phased array as described in and complies with Resolution **221 (Rev.WRC-07)** is used in the sharing studies as given below:

$G(\psi) = G_m - 3(\psi/\psi b)^2$	dBi	for	$0° \leq \psi \leq \psi_1$
$G(\psi) = G_m + L_N$	dBi	for	$\psi_1 < \psi \leq \psi_2$
$G(\psi) = X - 60 \log(\psi)$	dBi	for	$\psi_2 < \psi \leq \psi_3$
$G(\psi) = L_F$	dBi	for	$\psi_3 < \psi \leq 90°$

where:

$G(\psi)$:	gain at the angle ψ from the main beam direction (dBi)	
G_m :	maximum gain in the main lobe (dBi)	
ψ_b:	one-half of the 3 dB beamwidth in the plane considered (3 dB below G_m) (degrees)	
L_N :	near side-lobe level (dB) relative to the peak gain required by the system design, and has a maximum value of –25 dB	
L_F :	far side-lobe level, G_m – 73 dBi	
ψ_1 =	$\psi_b \sqrt{-L_N/3}$	degrees
ψ_2 =	$3.745\ \psi_b$	degrees
X =	$G_m + L_N + 60 \log(\psi_2)$ dBi	
ψ_3 =	$10^{(X - L_F)/60}$	degrees

The 3 dB beamwidth ($2\psi_b$) is estimated by:

$$(\psi_b)^2 = 7\,442/(10^{0.1 G_m}) \quad \text{degrees}^2;$$

The antenna roll-off factor of 60 dB per decade is used for these high performance multibeam phased array antennas in accordance with the antenna radiation mask as specified in Resolution **221 (Rev.WRC-07)**.

ANNEX 2: FREQUENCY ALLOCATIONS IN THE BAND 5850-7075 MHz

Allocation to services		
Region 1	**Region 2**	**Region 3**
…	…	…
5 850-5 925 FIXED FIXED-SATELLITE (Earth-to-space) MOBILE 5.150	**5 850-5 925** FIXED FIXED-SATELLITE (Earth-to-space) MOBILE Amateur Radiolocation 5.150	**5 850-5 925** FIXED FIXED-SATELLITE (Earth-to-space) MOBILE Radiolocation 5.150
5 925-6 700	FIXED FIXED-SATELLITE (Earth-to-space) 5.457A 5.457B MOBILE 5.4B02 5.149 5.440 5.458	
6 700-7 075	FIXED FIXED-SATELLITE (Earth-to-space) (space-to-Earth) 5.441 MOBILE 5.458 5.458A 5.458B 5.458C	
…	…	…

Table 25: Frequency allocations in the band 5850-7075 MHz

5.149 In making assignments to stations of other services to which the bands:
…,
6650-6675.2 MHz,

are allocated, administrations are urged to take all practicable steps to protect the radio astronomy service from harmful interference. Emissions from spaceborne or airborne stations can be particularly serious sources of interference to the radio astronomy service (see Nos. **4.5** and **4.6** and Article **29**). (WRC-2000)

5.150 The following bands:
…,
5725-5875 MHz (centre frequency 5800 MHz), and
…
are also designated for industrial, scientific and medical (ISM) applications. Radiocommunication services operating within these bands must accept harmful interference which may be caused by these applications. ISM equipment operating in these bands is subject to the provisions of No. **15.13**.

5.440 The standard frequency and time signal-satellite service may be authorized to use the frequency 4202 MHz for space-to-Earth transmissions and the frequency 6427 MHz for Earth-to-space transmissions. Such transmissions shall be confined within the limits of ± 2 MHz of these frequencies, subject to agreement obtained under No. **9.21**.

5.441 The use of the bands 4500-4800 MHz (space-to-Earth), 6725-7025 MHz (Earth-to-space) by the fixed-satellite service shall be in accordance with the provisions of Appendix **30B**. The use of the bands 10.7-10.95 GHz (space-to-Earth), 11.2-11.45 GHz (space-to-Earth) and 12.75-13.25 GHz (Earth-to-space) by geostationary-satellite systems in the fixed-satellite service shall be in accordance with the provisions of Appendix **30B**. The use of the bands 10.7-10.95 GHz (space-to-Earth), 11.2-11.45 GHz (space-to-Earth) and 12.75-13.25 GHz (Earth-to-space) by a non-geostationary-satellite system in the fixed-satellite service is subject to application of the provisions of No. **9.12** for coordination with other non-geostationary-satellite systems in the fixed-satellite service. Non-geostationary-satellite systems in the fixed-satellite service shall not claim protection from geostationary-satellite networks in the fixed-satellite service operating in accordance with the Radio Regulations, irrespective of the dates of receipt by the Bureau of the complete coordination or notification information, as appropriate, for the non-geostationary-satellite systems in the fixed-satellite service and of the complete coordination or notification information, as appropriate, for the geostationary-satellite networks, and No. **5.43A** does not apply. Non-geostationary-satellite systems in the fixed-satellite service in the above bands shall be operated in such a way that any unacceptable interference that may occur during their operation shall be rapidly eliminated. (WRC-2000).

5.457A In the bands 5925-6425 MHz and 14-14.5 GHz, earth stations located on board vessels may communicate with space stations of the fixed-satellite service. Such use shall be in accordance with Resolution **902 (WRC-03)**. (WRC-03).

5.457B In the bands 5925-6425 MHz and 14-14.5 GHz, earth stations located on board vessels may operate with the characteristics and under the conditions contained in Resolution **902 (WRC-03)** in Algeria, Saudi Arabia, Bahrain, Comoros, Djibouti, Egypt, United Arab Emirates, the Libyan Arab Jamahiriya, Jordan, Kuwait, Morocco, Mauritania, Oman, Qatar, the Syrian Arab Republic, Sudan, Tunisia and Yemen, in the maritime mobile-satellite service on a secondary basis. Such use shall be in accordance with Resolution **902 (WRC-03)**. (WRC-03).

5.458 In the band 6425-7075 MHz, passive microwave sensor measurements are carried out over the oceans. In the band 7075-7250 MHz, passive microwave sensor measurements are carried out. Administrations should bear in mind the needs of the Earth exploration-satellite (passive) and space research (passive) services in their future planning of the bands 6425-7025 MHz and 7075-7250 MHz.

5.458A In making assignments in the band 6700-7075 MHz to space stations of the fixed-satellite service, administrations are urged to take all practicable steps to protect spectral line observations of the radio astronomy service in the band 6650-6675.2 MHz from harmful interference from unwanted emissions.

5.458B The space-to-Earth allocation to the fixed-satellite service in the band 6700-7075 MHz is limited to feeder links for non-geostationary satellite systems of the mobile-satellite service and is subject to coordination under No. **9.11A**. The use of the band 6700-7075 MHz (space-to-Earth) by feeder links for non-geostationary satellite systems in the mobile-satellite service is not subject to No. **22.2**.

5.458C Administrations making submissions in the band 7025-7075 MHz (Earth-to-space) for geostationary-satellite systems in the fixed-satellite service after 17 November 1995 shall consult on the basis of relevant Recommendations ITU-R with the administrations that have notified and brought into use non-geostationary-satellite systems in this frequency band before 18 November 1995 upon request of the latter administrations. This consultation shall be with a view to facilitating shared operation of both geostationary-satellite systems in the fixed-satellite service and non-geostationary-satellite systems in this band.

5.457C In Region 2 (except Brazil, Cuba, French Overseas Departments and Communities, Guatemala, Paraguay, Uruguay and Venezuela), the band 5925-6700 MHz may be used for aeronautical mobile telemetry for flight testing by aircraft stations (see No. **1.83**). Such use shall be in accordance with Resolution **416 (WRC-07)** and shall not cause harmful interference to, nor claim protection from, the fixed-satellite and fixed services. Any such use does not preclude the use of these bands by other mobile service applications or by other services to which these bands are allocated on a co-primary basis and does not establish priority in the Radio Regulations. (WRC-07)

ANNEX 3: FS TECHNICAL CHARACTERISTICS

Frequency Band (GHz)	5.850-7.075		5.925-6.425	5.9-6.4			5.925-6.425	5.925-6.425	6.425-7.11	
Modulation	64-QAM		16-QAM	64-QAM			RBQPSK	64-QAM	QPSK	16-QAM
Capacity	45 Mbit/s	135 Mbit/s	52 Mbit/s	45 Mbit/s	90 Mbit/s	135 Mbit/s	140 Mbit/s	140 Mbit/s	34 Mbit/s	140 Mbit/s
Channel spacing (MHz)	10	30	20	10	20	30	90	29.65	20	40
Antenna gain (maximum) (dBi)	43	43	45	46	46	46	45	45	45	45
Feeder/multiplexer loss (minimum) (dB)	3	3	T:7.0 R:4.0	0	0	0	4	5.5	5	5
Antenna type	Dish	Dish	Horn	Dish	Dish	Dish	3.7 m dish	3.7 m dish	3.7 m dish	3.7 m dish
Maximum Tx output power (dBW)	-1	4	-9.8	+3	+3	+3	6	2	0	0
e.i.r.p.. (maximum) (dBW)	39	44	28.2	49	49	49	47	41.5	40	40
Receiver IF bandwidth (MHz)			16.65	10	20	30	56	29	26	44
Receiver noise figure (dB)			4.2	3	3	3	6	4	4	4
Receiver thermal noise (dBW)	–130	–125	–128.1	–131	–128	–126	–122	–127	–128	–126
Nominal Rx input level (dBW)			–-73	–60	–60	–60	–65	–63	–68	–65
Rx input level for 1×10^{-3} BER (dBW)	–103	–102		–109	–106	–104	–105	–103	–114.5	–105
Nominal long-term interference (dBW)	–143 (4)	–138 (4)		–141	–138	–136	–132	–137	–138	–136
Spectral density (dB(W/MHz))	–153	–153		–151	–151	–151	–149	–152	–152	–152
Refer to Notes	Table 10 of ITU-R Rec.F.758		Table 12 of ITU-R Rec.F.758	(1), (2) Table 11 of ITU-R Rec.F.758	(1), (2) Table 11 of ITU-R Rec.F.758	(1), (2) Table 11 of ITU-R Rec.F.758	(1), (3) Table 11 of ITU-R Rec.F.758	(1), (2) Table 11 of ITU-R Rec.F.758	(1), (2) Table 11 of ITU-R Rec.F.758	(1), (2) Table 11 of ITU-R Rec.F.758

Table 26: FS system parameters for sharing in the frequency band 5850-7075 MHz

(1) Specified interference will reduce system *C*/*N* by 0.5 dB (interference 10 dB below receiver thermal noise floor).

(2) The specified interference level is total power within the receiver bandwidth.

(3) The specified interference level should be divided by the receiver bandwidth to obtain an average spectral density. The interference spectral density, averaged over any 4 kHz within the receiver bandwidth, must not exceed this value.

(4) Objective for FS systems employing space diversity ($I/N = -13$ dB).

Frequency Band (GHz)	6.4-7.1		6.570-6.870		6.425-7.11		6.5-6.9		
Modulation	64-QAM		4-PSK	16-QAM	16-QAM		128-TCM		
Capacity	90 Mbit/s	135 Mbit/s	10 Mbit/s	52 Mbit/s	34 Mbit/s	2 × 34 Mbit/s	3.1 Mbit/s	12.4 Mbit/s	24.7 Mbit/s
Channel spacing (MHz)	20	40	20	20	20	20	0.8	2.5	5
Antenna gain (maximum) (dBi)	47	47	45	45	45	45	47	47	47
Feeder/multiplexer loss (minimum) (dB)	0	0	T:2.5 R:5.5	T:3.0 R:5.0	Tx:1.5 Rx:2	Tx:1.5 Rx:2	0	0	0
Antenna type	Dish	Dish	Dish	Dish	Dish	Dish	Dish	Dish	Dish
Maximum Tx output power (dBW)	+3	+3	3	3	0	0	+1	+1	+1
e.i.r.p. (maximum) (dBW)	50	50	45.5	45	43.5	43.5	48	48	48
Receiver IF bandwidth (MHz)	20	30	12.5	17.5	24	24	0.8	2.5	5
Receiver noise figure (dB)	3	3	5	5	4	4	3	3	3
Receiver thermal noise (dBW)	–128	–125	–128.0	–126.6	–130	–127	–142	–137	–134
Nominal Rx input level (dBW)	–60	–60	–92.5	–87.5			–60	–60	–60
Rx input level for 1×10^{-3} BER (dBW)					–111.5	–108.5			
Nominal long-term interference (dBW)					–140	–137			
Spectral density (dB(W/MHz))					–149.8	–149.7			
Refer to Notes	Table 12 of ITU-R Rec.F.758				Table 13 of ITU-R Rec.F.758		Table 12 of ITU-R Rec.F.758		

Table 27: FS system parameters for frequency sharing in the frequency band 5850-7075 MHz

ANNEX 4: LIST OF REFERENCES

[1] Recommendation ITU-R F.758-4 - Considerations in the development of criteria for sharing between the fixed service and other services.

[2] Recommendation ITU-R F.1245-1 – Mathematical model of average and related radiation patterns for line-of-sight point-to-point radio-relay system antennas for use in certain coordination studies and interference assessment in the frequency range from 1 GHz to about 70 GHz.

[3] Recommendation ITU-R S.672-4 - Satellite antenna radiation pattern for use as a design objective in the fixed-satellite service employing geostationary satellites.

[4] Recommendation ITU-R S.1432-1 - Apportionment of the allowable error performance degradations
to fixed-satellite service (FSS) hypothetical reference digital paths arising from time invariant interference for systems operating below 30 GHz.

[5] ECC/REC/(08)01 – Use of the band 5855-5875 MHz for Intelligent Transport Systems (ITS).

[6] ECC/DEC/(08)01 of 14 March 2008 - On the harmonised use of the 5875-5925 MHz frequency band for Intelligent Transport Systems (ITS).

[7] Recommendation ITU-R M.1453-2 - Intelligent transport systems – dedicated short range communications at 5.8 GHz.

[8] ECC Report 101 – Compatibility studies in the band 5855-5925 MHz between Intelligent Transport Systems (ITS) and other systems.

[9] Recommendation ITU-R F.1336-2 - Reference radiation patterns of omnidirectional, sectoral and other antennas in point-to-multipoint systems for use in sharing studies in the frequency range from 1 GHz to about 70 GHz.

[10] Recommendation ITU-R RS.1861 - Typical technical and operational characteristics of Earth exploration-satellite service (passive) systems using allocations between 1.4 and 275 GHz.

[11] Recommendation ITU-R RS.1029-2 - Interference criteria for satellite passive remote sensing.

[12] Recommendation ITU-R RS.1813 - Reference antenna pattern for passive sensors operating in the Earth exploration-satellite service (passive) to be used in compatibility analyses in the frequency range 1.4-100 GHz.

[13] Recommendation ITU-R RA.769-2 - Protection criteria used for radio astronomical measurements.

[14] Recommendation ITU-R RA.1031-2 - Protection of the radio astronomy service in frequency bands shared with other services.

[15] Recommendation ITU-R F.1094 - Maximum allowable error performance and availability degradations to digital fixed wireless systems arising from radio interference from emissions and radiations from other sources.