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Sharing and compatibility studies of HAPS systems in the fixed service for the frequency band 6 440-6 520 MHz

F Series

Fixed service

International Telecommunication Union

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Note*: This ITU-R Report was approved in English by the Study Group under the procedure detailed in Resolution ITU-R 1.*

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REPORT ITU-R F.2437-0

Sharing and compatibility studies of HAPS systems in the fixed service for the frequency band 6 440-6 520 MHz

(2018)

Summary

This Report provides sharing and compatibility studies between High Altitude Platform Station (HAPS) and systems in the Fixed, Fixed Satellite, Mobile, Earth Exploration Satellite Services and Radio Astronomy operating in the 6 440-6 520 MHz frequency range.

The studies develop power flux-density (pfd) levels, which if met by HAPS, will protect systems operating in the Fixed Service (FS) and Mobile Service (MS). The studies also develop an equivalent isotropically radiated power (e.i.r.p.) limit for HAPS that will protect the Fixed Satellite Service (FSS). For the protection of the Earth Exploration Satellite Service (EESS) that operates over oceans, the studies develop methods that can be applied by HAPS to provide full protection to the EESS sensors.

The studies address the impact of HAPS systems operating in the HAPS-to-ground direction.

1 Introduction

This Report includes the sharing and compatibility studies of HAPS systems in the 6 440-6 520 MHz frequency range with services to which the band is allocated on a primary basis, with EESS passive service and with Radio Astronomy. Even though the EESS passive service is not allocated in the 6 440-6 520 MHz band, footnote No. **5.458** of the Radio Regulations recognizes that this band is used for microwave sensor measurements.

This Report provides the sharing and compatibility studies called for under *further resolves* 1, 2 and 3 of Resolution **160 (WRC-15)**, to ensure the protection of the existing services allocated to the frequency bands to be shared with HAPS, taking into account the relevant footnotes of Article **5** of the RR which include terms and conditions on the use of certain frequency bands, as well as Resolution **145 (Rev.WRC-12)**.

2 Glossary

CDF	Cumulative distribution function
DL	Down link
e.i.r.p.	Equivalent isotopically radiated power
GW	Gateway (provides feeder link service between ground and HAPS)
HAPS	High altitude platform station
LHCP	Left hand circular polarisation
pfd	power flux density
RHCP	Right hand circular polarisation
TX	Transmitter

3 Allocation information in the 6 440-6 520 MHz frequency range

The Radio Regulation Table of Allocations is provided for reference below.

TABLE 1

Radio Regulations Table of Allocations

Allocation to services		
Region 1	**Region 2**	**Region 3**
5 925-6 700	FIXED 5.457 FIXED-SATELLITE (Earth-to-space) 5.457A 5.457B MOBILE 5.457C 5.149 5.440 5.458	

5.458 In the band 6 425-7 075 MHz, passive microwave sensor measurements are carried out over the oceans. In the band 7 075-7 250 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 6 425-7 075 MHz and 7 075-7 250 MHz.

4 Technical characteristics

4.1 Technical and operational characteristics of HAPS systems operating in the 6 440-6 520 MHz

The technical and operational characteristics of HAPS systems can be found in Report ITU-R F.2439.

4.2 Technical and operational characteristics of fixed service operating in the 6 440-6 520 MHz

The technical characteristics of the fixed wireless system were obtained from Recommendation ITU-R F.758-6 and are summarized in the following Table.

TABLE 2

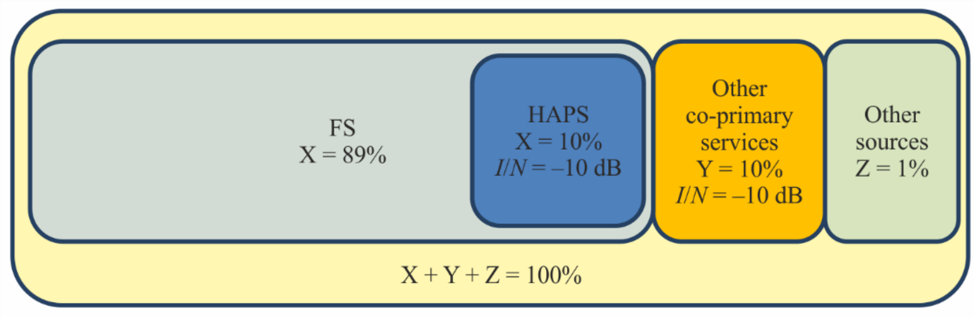
FS system parameters for frequency sharing in the frequency band 5 850–7 075 MHz

Frequency band (GHz)	6 425-7 125	
Modulation	QPSK	64-QAM
Antenna gain range (dBi)	35.3…43.9	32.6…47.4
e.i.r.p. range (dBW)	27.1…42.2	15.8…48.8
e.i.r.p. density range (dB(W/MHz))	14.1…29.1	-0.2…32.7
Receiver noise power density (dB(W/MHz))	–139	–139.5…–139
Nominal long-term interference power density (dB(W/MHz))	–139 + *I*/*N*	–139…–139.5 + *I*/*N*
Interference Power Spectral density (dB(W/MHz)) that could be exceeded by no more than 20% of the time	–149	–149…–149.5
Azimuth distribution	between –180 and 180 and uniform	
Elevation distribution	Normal distribution (median 0.01° and standard deviation 1.5)	
Sources	Table 6 of Rec. ITU-R F.758-6 and Rec. ITU-R F.2086-0	

Recommendation ITU-R F.1094 divides the allowable performance objective into an element of 89% for the FS portion, 10% for frequency sharing on a primary basis and 1% for all other sources of interference. HAPS are part of the FS portion and it is proposed that 10% of the allowable performance objective is allowed for HAPS which corresponds to an *I*/*N* of –10 dB (see Recommendation ITU-R F.758-6). Figure 1 provides an illustration of the protection criteria apportionment.

FIGURE 1

Illustration of the long-term protection criteria apportionment



Report F.2437-01

Recommendation ITU-R F.1245-2 contains a mathematical model of average (and other related) radiation patterns for line-of-sight point-to-point radio-relay system antennas for use in the frequency range from 1 to about 70 GHz. This Recommendation may be used in the absence of specific information on the radiation pattern of the line-of-sight radio-relay system antennas.

For a FS functioning at 6 GHz, it has been assumed that the FS antenna was located at a height of 6-10 meters above the ground level.

4.3 Technical and operational characteristics of fixed satellite service (Earth-to-space) operating in the 6 440-6 520 MHz

TABLE 3

FSS Uplink Parameters (interfered with)

Frequency range (GHz)	6.44-6.64	6.44-6.64
Carrier	Carrier #11	Carrier #12
Noise bandwidth (MHz)	1.0-20	1.0-20
Peak receive antenna gain (dBi)	20	36.4
Antenna receive gain pattern and (3-dB) beamwidth	Section 1.1 of Annex 1 of Rec. ITU-R S.672-4 LS = –25 BW = 1.7	Section 1.1 of Annex 1 of Rec. ITU-R S.672-4 LS = –25 BW = 1.5
System receive noise temperature (K)	400	400
Interference to noise ratio *I*/*N* (dB) [1]	–10.5	–10.5

[1] In the study an *I*/*N* of –10.5 dB is used for 100% of the cases and therefore is even more constraining than the FSS protection criteria that is provided by ITU-R Working Party 4A: *I*/*N* of –6 dB, *I*/*N* of –9 dB and *I*/*N* = –10.5 dB that could be exceeded no more than respectively 0.0004%, 0.08% and 20% of the time or location.

TABLE 4

FSS uplink parameters (interferer)

Frequency range (GHz)	6.44-6.64	6.44-6.64
Earth station carrier	Carrier #11	Carrier #12
Peak transmit antenna gain (dBi)	39.9	57.2
Peak transmit power spectral density (clear sky) (dB(W/Hz))	–50	–33 (40 kHz BW) –43 (36 MHz BW)
Antenna gain pattern	Rec. ITU-R S.465-6	Rec. ITU-R S.465-6
Minimum elevation angle of transmit earth station	5	5

4.4 Technical and operational characteristics of mobile service operating in the 6 440-6 520 MHz

TABLE 5

MS technical parameters

Receiver characteristics	**Units**	**Value**
Receiver bandwidth	MHz	10
Receiver sensitivity	dBm	–82
Antenna gain (see Note 1)	dBi	8
Receiver sensitivity at antenna input	dB(mW/MHz)	–100
C/I	dB	6
Allowable interfering power at receiver input	dB(mW/MHz)	–98
Allowable interfering power at receiver antenna input	dB(mW/MHz)	–106
Transmitter characteristics		
Bandwidth	MHz	10
Tx out, e.i.r.p.	dBm	33
Tx out e.i.r.p. per MHz	dB(mW/MHz)	23
Assumed value for TPC	dB	8
Net Tx out e.i.r.p.	dB(mW/MHz)	15
Antenna gain	dBi	8
Source	Report ITU-R F.2240 Annex 3	

NOTE – The value of 8 dBi is used when considering emissions received or transmitted in the main beam of the MS station.

In the absence of mobile technical parameters, studies were performed using mobile characteristics provided in Report ITU-R F.2240, Annex 3, that provides non-safety ITS characteristics for use in the band 5 875-5 925 MHz.

Recommendation ITU-R F.1336-2 specifies the peak and average antenna patterns of omni-directional, sectoral and directional antennas in point-to-multipoint systems which may be used in sharing studies in the frequency range 1 GHz to about 70 GHz. The antenna performance characteristics specified in this Report are used for the analysis.

Recommendation ITU-R F.1336-2 specifies the antenna gain in dBi at elevation angle θ in degrees to be as follows:

$$G(\theta) = \max\left[G_1(\theta), G_2(\theta)\right]$$

with:

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

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

where:

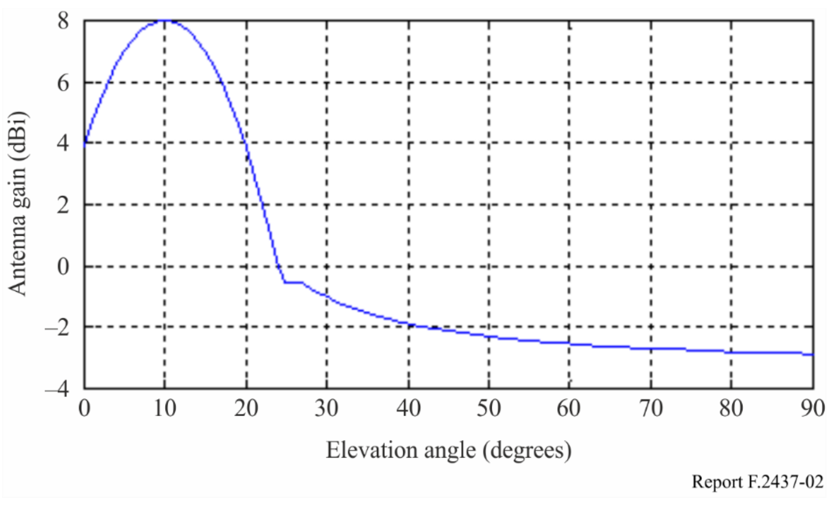
- G_0: the maximum gain in or near the horizontal plane (dBi)
- θ: absolute value of the elevation angle relative to the angle of maximum gain (degrees)
- θ_3: the 3 dB beamwidth in the vertical plane (degrees)
- k = 1.2 the side lobe factor.

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

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

FIGURE 2

MS antenna gain



4.5 Technical and operational characteristics of passive microwave sensors operating in 6 440-6 520 MHz

4.5.1 Background

The EESS passive service it is not allocated in the 6 440-6 520 MHz band however the RR recognize that microwave sensor measurements are carried out in the band.

Provision No. **5.458** of the Radio Regulations states that in the band 6 425-7 075 MHz passive microwave sensor 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 this band.

4.5.2 Specific EESS (passive) considerations

Currently the band 6 425-7 075 MHz is used by only one passive microwave sensor; however, there are at least 3 other systems planned for operation in the near future.

Table 6 below, summarizes the parameters of passive sensors that are or will be operating in the 6.425-7.25 GHz band. These parameters were obtained from the relevant parts of Recommendation ITU-R RS.1861.

The level of interference into a passive radiometer on board a space station will depend on, among other things, the pointing direction and antenna pattern of the HAPS. This could result in an area where HAPS ground stations may not be deployed or other limitations may apply.

A single passive sensor cannot by itself identify how much energy is radiated by each substance in its field of view. For this reason, usable data are derived by comparing measurements from multiple sensors operating at multiple frequencies. By performing radiometric measurements at multiple frequencies, each type of natural emitter (e.g. water vapour, 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. As a result, the 6-7 GHz band is the most suitable for relatively higher spatial resolution measurements. 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 most suitable for such measurements.

TABLE 6

EESS (passive) sensor characteristics in the 6 425-7 250 MHz band	**Sensor B1**	**Sensor B2**	**Sensor B3**	**Sensor B4**
Sensor type	**Conical scan**			
Orbit parameters				
Altitude (km)	705	**828**	835	699.6
Inclination (degrees)	98.2	**98.7**	98.85	98.186
Eccentricity	0.0015	**0**	0	0.002
Repeat period (days)	16	**17**	N/A	16
Sensor antenna parameters				
Number of beams	1			
Reflector diameter (m)	1.6	**2.2**	0.6	2.0
Maximum beam gain (dBi)	38.8	41.1 *	30.2 *	40.6
Polarization	**V, H**			
–3 dB beamwidth (degrees)	2.2	**1.65**		1.8
Off-nadir pointing angle (degrees)	47.5	**46.8**	55.4	47.5

TABLE 6 (*end*)

EESS (passive) sensor characteristics in the 6 425-7 250 MHz band	Sensor B1	Sensor B2	Sensor B3	Sensor B4
Beam dynamics (rpm)	40	**31.6**	2.88 s scan period	40
Incidence angle at Earth (degrees)	55°	**55.7°**	65°	55°
–3 dB beam dimensions (km)	40 (cross-track)	**24**		35 (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 (km)	1 450	**1 700**	2 000	1 450
Sensor antenna pattern	**See Rec. ITU-R RS.1813**			
Cold calibration ant. gain (dBi)	25.1	**N/A**		25.6
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 (ms)	2.5	**5**	N/A	2.5
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 (km)	43	**15-50**	38	35
Vertical resolution (km)	74	**24**	38	61

* The maximum antenna Gain is missing in Recommendation ITU-R RS.1861 and has been computing using the reflector diameter and the antenna efficiency of 55% as the one of sensors B1 and B4.

According to Recommendation ITU-R RS.2017-0, the interference threshold is −166 dBW for a bandwidth of 200 MHz. This interference criterion has to be understood as an aggregate basis from all sources of interference.

Still according to Recommendation ITU-R RS.2017-0, this criterion may be exceeded less than 0.1% of the area or the time, calculated when the sensor is performing measurements over a reference area of 10 000 000 km^2.

4.6 Technical and operational characteristics of radio astronomy operating in 6 650-6 675.2 MHz

To protect Radio Astronomy service in the band 6 650-6 675.2 MHz from unwanted emission of HAPS in the band 6 440-6 520 MHz the resulting pfd of a HAPS emission at RAS receivers shall not exceed –210 dB(W/(m^2 · 50 kHz)) for more than 2% of the time. In MHz this corresponds to −197 dB(W/(m^2 · MHz)). This level is based on 30 dBi RAS antenna gain towards HAPS because of the probability of main beam coupling.

NOTE – The 30 dBi RAS antenna gain towards the HAPS relates to the time percentage of 2% associated to the RAS protection criteria. By assuming an inter-HAPS distance of 100 km, a total maximum of 81 HAPS could be seen by a RAS station. The RAS station while operating cannot receive interference for more than 2% of time, which is the same as 2% of its field of view. This 2% field of view area divided between each HAPS amounts to:

$$\Omega = \frac{2\pi}{N_{HAPS}} \times \frac{2}{100} = 0.0016\ steradian$$

From this area around each HAPS (in which interference can happen), the cone angle can be determined:

$$\theta = \cos^{-1}\left(1 - \frac{\Omega}{2\pi}\right) = 1.27°$$

When applying RAS antenna pattern Recommendation ITU-R SA.509, this 1.27° corresponds to a gain of about 30 dBi (32-25 log(φ)).

TABLE 7

List of radio astronomy stations operating, or planning to operate, in the band 6 650-6 675.2 MHz

Region 1

Country	Name	N Latitude	E Longitude	Antenna size (m)
Belgium	Humain (planned use)	50° 15' 12"	50° 11' 31"	6
Finland	Metsahövi (planned use)	60° 13' 04"	24° 23' 37"	13.7
Germany	Effelsberg	50° 31' 29"	06° 53' 03"	100
	Wettzell VGOS1,2	49° 08' 38"	12° 52' 40"	13.2, 13.2
Italy	Medicina	44° 31' 14"	11° 38’ 49"	32
	Sardinia	39° 29' 34"	09° 14' 42"	64
Latvia	Ventspils	57° 33' 12"	21° 51' 17"	16,32
South Africa	SKA1-MID (planned)	–30° 42' 47"	21° 26' 38"	133 × 15 64 × 13.5
Spain	Yebes	40° 31' 27"	–03° 05′ 13"	13, 40
Sweden	Kiruna	67° 51' 38"	20° 26' 07"	16
	Onsala	57° 23' 45"	11° 55' 35"	20
UK	MERLIN Cambridge	52° 10' 01"	00° 02' 20"	32
	MERLIN Darnhall	53° 09′ 23"	–02° 32' 09"	25
	MERLIN Defford	52° 06′ 01"	–02° 08' 39"	25
	MERLIN Jodrell Bank	53° 14′ 10"	–02° 18' 26"	30, 76
	MERLIN Knockin	52° 47' 25"	–02° 59' 50"	25
	MERLIN Pickmere	53° 17′ 19"	–02° 26' 44"	25

TABLE 7 (*continued*)

Region 2

Country	Name	N Latitude	E Longitude	Antenna Size (m)
Brasil	Itapetinga	–23° 11' 05"	–46° 33' 28"	14
Canada	Algonquin Radio Observatory	45° 57' 19"	–78° 04' 23"	46
USA	Arecibo	18° 20' 39"	–66° 45' 10"	305
	Allen Telescope Array	40° 49' 01"	–121° 28' 12"	42 × 6
	GGAO Greenbelt	39° 06' 00"	–76° 29' 24"	12
	Green Bank Telescope	38° 25' 59"	–79° 50' 23"	100
	Haystack	42° 36' 36"	–71° 28' 12"	18
	Kokee Park	22° 07' 34"	–159° 39' 54"	20
	Jansky VLA	33° 58' 22" to 34° 14' 56"	–107° 24' 40" to –107° 48' 22"	27 × 25
	VLBA Brewster, WA	48° 07' 52"	–119° 41' 00"	25
	VLBA Fort Davis, TX	30° 38' 06"	–103° 56' 41"	25
	VLBA Hancock, NH	42° 56' 01"	–71° 59' 12"	25
	VLBA Kitt Peak, AZ	31° 57' 23"	–111° 36' 45"	25
	VLBA Los Alamos, NM	35° 46' 30"	–106° 14' 44"	25
	VLBA Mauna Kea, HI	19° 48' 05"	–155° 27' 20"	25
	VLBA North Liberty, IA	41° 46' 17"	–91° 34' 27"	25
	VLBA Owens Valley, CA	37° 13' 54"	–118° 16' 37"	25
	VLBA Pie Town, NM	34° 18' 04"	–108° 07' 09"	25
	VLBA St. Croix, VI	17° 45' 24"	–64° 35' 01"	25
	Goldstone	35° 25' 33"	–116° 53' 22"	70.3, 34
	Owens Valley Radio Observatory	37° 13' 54"	–118° 16' 35"	10

TABLE 7 (*end*)

Region 3

Country	**Name**	**N Latitude**	**E Longitude**	**Antenna size (m)**
Australia	Parkes	–33º 00' 00"	148º 15' 44"	64
	Katherine	–14º 22' 32"	132º 09' 09"	12
	Mopra	–31º 16' 04"	149º 05' 58"	22
	ATCA (Narrabri)	–30º 59' 52"	149º 32' 56"	6 × 22
	Tidbinbilla	–35º 24' 18"	148º 58' 59"	70, 34
	Hobart (Mt. Pleasant)	–42º 48' 18"	147º 26' 21"	26
	Ceduna	–31º 52' 05"	133º 48' 37"	30
	Yarragadee	–29º 02' 44"	115º 20' 44"	12
China	Miyun	40º 33' 29"	116° 58' 33"	50
	Tianma	31° 05' 13"	121° 09' 48"	65
	Huairong SBRS	40º 18' 58.3"	116°35' 44"	7.3, 3.2, 2
	Nanjing SBRS	32º 02' 00"	118°50' 00"	2
	CSRH	42º 12' 31.3"	115°14' 44"	4.5, 2
	QTT	43º 36' 04"	89° 40' 57"	110
Japan	Ishigakijima	24° 24' 44"	124° 10' 16"	20
	Iriki	31° 44' 52"	130° 26' 24"	20
	Yamakawa	31° 12' 15"	130° 37' 00"	8
	Yamaguchi	34° 12' 58"	131° 33' 26"	34
	Yamaguchi	34° 12' 58"	131° 33' 26"	32
	Usuda	36° 07' 57"	138° 21' 46"	64
	Koganei	35° 42' 28"	139° 29' 17"	2.4
	Sansouken Tsukuba	36° 03' 33"	140° 08' 05"	1.6
	Ishioka	36° 12' 33"	140° 13' 08"	13.2
	Kashima	35° 57' 21"	140° 39' 36"	34
	Ibaraki Hitachi	36° 41' 51"	140° 41' 32"	32
	Ibaraki Takahagi	36° 41' 55"	140° 41' 41"	32
	Mizusawa	39° 08' 01"	141° 07' 57"	20
Korea	KSWC (Jeju)	33º 25' 40"	126º 17' 45"	1.8
	SGOC (Sejong)	36º 31' 22"	127º 18' 12"	22
	K-SRBL	36º 24' 00"	127º 22' 12"	2 × 2
	KVN-Yonsei	37º 33' 55"	126º 56' 27"	20
	KVN-Ulsan	35º 32' 44"	129º 14' 59"	20
	KVN-Tamna	33º 17' 21"	126º 27' 34"	20
New Zealand	Warkworth	–36º 25' 59"	174º 39' 52"	30, 12

5 Sharing and compatibility studies

Annex 1: Sharing and compatibility of Fixed Service and HAPS systems operating in the 6 440-6 520 MHz frequency range

Annex 2: Sharing and compatibility of Fixed Satellite Service (Earth-to-space) and HAPS systems operating in the 6 440-6 520 MHz frequency range

Annex 3: Sharing and compatibility of Mobile Service and HAPS systems operating in the 6 440-6 520 MHz frequency range

Annex 4: Compatibility of EESS (passive) and HAPS systems operating in the 6 440-6 520 MHz frequency range

Annex 5: Compatibility of Radio Astronomy in the band 6 650-6 675.2 MHz and HAPS systems operating in the 6 440-6 520 MHz frequency range.

Annex 1
(FS)

Sharing and compatibility of fixed service and HAPS systems operating in the 6 440-6 520 MHz frequency ranges

1 Technical analysis

TABLE 8

Scenario considered

HAPS to FS	X
FS to HAPS ground station	X

1.1 Summary

This study aims to define the maximum pfd level from HAPS versus elevation angle in order to protect FS stations receivers. In the analysis of a single HAPS being visible to an FS receiver, the HAPS is pointing in the direction of the FS receiving station and the elevation angle and antenna azimuth are treated as variable parameters. The maximum pfd value that satisfies the FS protection requirements is used to derive the pfd mask versus elevation angle, which meets the protection criteria of the FS. For the case of multiple HAPS visible to an FS station the pfd mask derived for the single HAPS case is used. Using the single HAPS pfd mask, the maximum pfd level at each FS location is determined by taking into account the elevation angle of each FS station antenna towards each HAPS. Then, the aggregate interference from all visible HAPS into each FS antenna is calculated. A maximum number of 50 HAPS within the visibility of each FS station is assumed. HAPS systems in this band are to be used for specific applications with low-density HAPS deployment requirements.

1.2 Analysis

1.2.1 Impact from transmitting HAPS into FS receiving stations

1.2.1.1 Impact from a single transmitting HAPS into FS receiving station

The following steps have been performed to derive such pfd mask versus elevation angle taking into account the impact of a single HAPS emission:

Step 1: Compute the FS antenna gain towards the HAPS based on the following input parameters.

– 0° is taken for the elevation angle towards the HAPS;

– 0° is taken for the azimuth towards the HAPS;

– FS station antenna pointing azimuth: random variable with a uniform distribution between –180° to 180°;

– FS station antenna pointing elevation: random variable with a normal distribution (median 0.01 and standard deviation 1.5);

– FS maximum antenna gain (from Recommendation ITU-R F.1245-2): random variable with a uniform distribution between 32.6 dBi and 47.4 dBi.

Step 2: Compute and store the maximum possible HAPS pfd level in dB(W/(m^2 · MHz)) at the FS station using the following equation:

$$I_{max} = pfd_{max} + 10 \times \log_{10}\left(\frac{\lambda^2}{4\pi}\right) + G_r(\theta) - L_{Rain} - L_{atm}$$

$$pfd_{max} = I_{max} + 10 \times \log_{10}\left(\frac{4\pi}{\lambda^2}\right) - G_r(\theta) + L_{Rain} + L_{atm}$$

where:

I_{max} : maximum interference level (–149.5 dB(W/MHz)) (long-term protection criteria)

G_r : FS antenna gain towards the HAPS based on Recommendation ITU-R F.1245 which include a polarisation loss of 1.7 dB in the main beam of FS (3 dB beamwidth) (see step 1)

θ : angle between the vector FS → HAPS and FS antenna main beam pointing vector.

In C band, the rain attenuation and the gases atmospheric attenuation are considered negligible and therefore the above equation providing the maximum allowable pfd can be simplified as follows:

$$pfd_{max} = I_{max} + 10 \times \log_{10}\left(\frac{4\pi}{\lambda^2}\right) - G_r(\theta)$$

Step 3: Redo step 1 and 2 sufficiently to obtain a stable pfd cumulative distribution function (CDF) curve and store it.

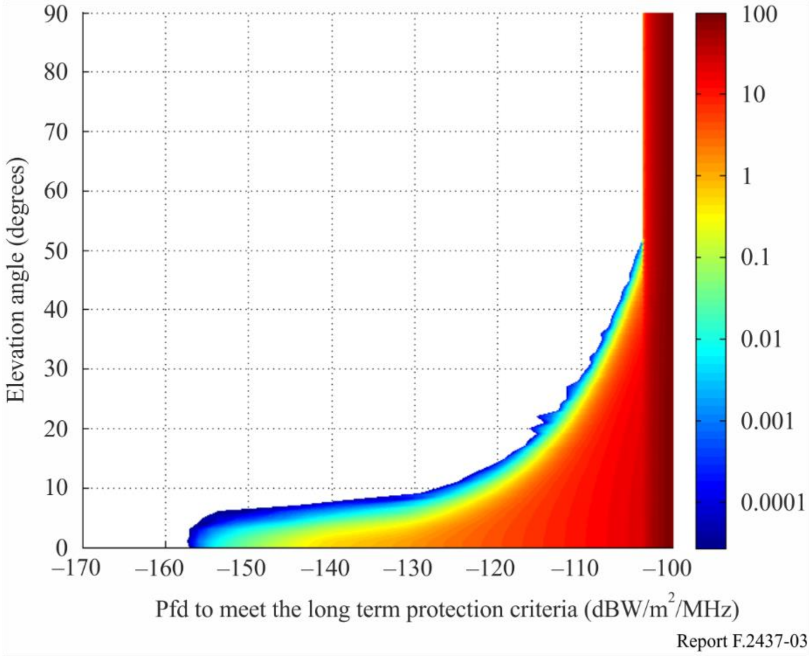
Step 4: Redo step 1 to 3 with an increased elevation angle towards the HAPS of 1 degree.

Step 5: Redo step 1 to 4 until the elevation angle towards the HAPS is 90 degrees.

The following Figure provides the results.

FIGURE 3

Maximum pfd level CDF to meet the FS protection criteria



Step 6: Determine the pfd mask versus elevation to protect FS station receiver in the case of a single HAPS is visible to the FS station.

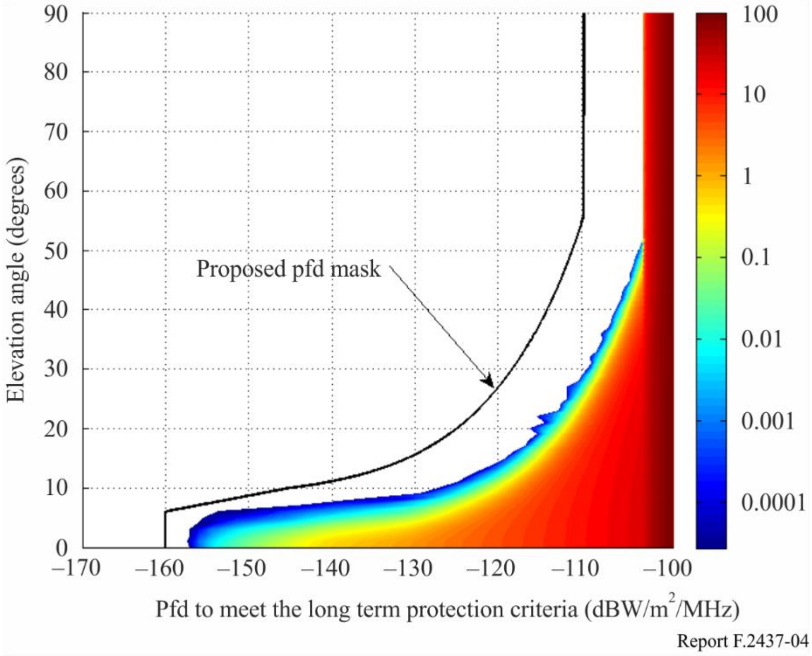
The following pfd mask in dB(W/(m^2 · MHz)) at the Earth surface should therefore be sufficient to protect FS station receivers from one HAPS emissions:

–160	for	$0° \leq \theta < 6°$
$3.75\theta – 182.5$	for	$6° \leq \theta < 10°$
$–152.5 + 25.5 \log(\theta\text{-}8)$	for	$10° \leq \theta < 56°$
–109.63	for	$56° \leq \theta \leq 90°$

where θ is the angles of arrival of the incident wave above the horizontal plane, in degree.

FIGURE 4

Proposed pfd mask versus elevation angle



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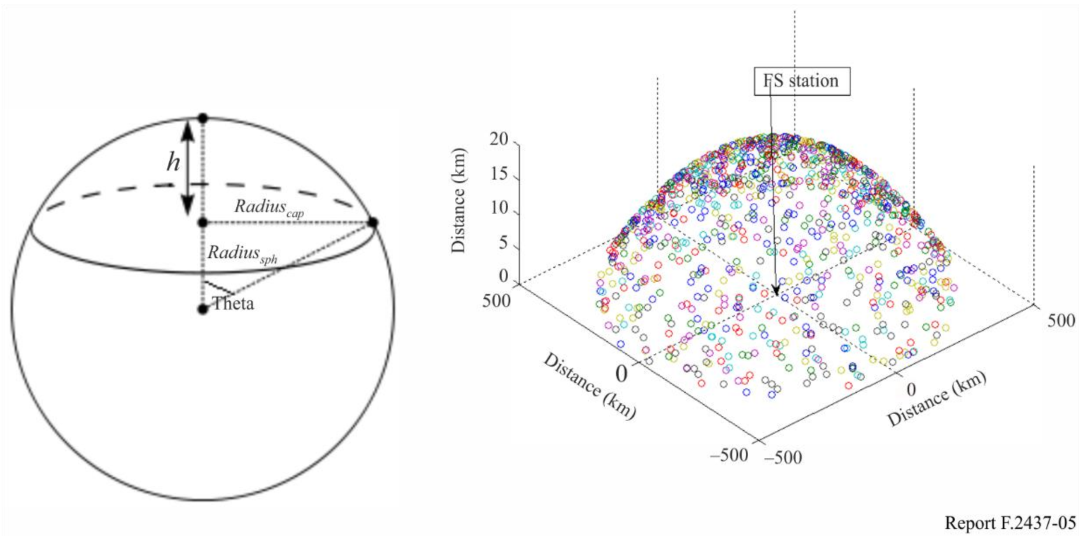
1.2.1.2 Aggregate impact from transmitting HAPS into FS receiving station

The following steps have been performed to define the aggregate impact of several HAPS being visible and compare the results with the single HAPS analysis:

Step 1: Locate N HAPSs uniformly distributed on the spherical cap visible from the FS station (see Fig. 5 below).

FIGURE 5

HAPS uniformly distributed on a spherical cap



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where:

h : HAPS altitude (20 km)

$Radius_{sph}$: Earth radius plus 20 km

$Radius_{cap}$: distance between the HAPS and the FS when the HAPS is seen from the FS station with an elevation angle of 0 degrees.

Step 2: Compute, for each HAPS from step 1, the angle between the horizontal plane at the FS station location and the vector from the FS station location toward the HAPS (elevation angle: angle of arrival above the horizontal plane).

Step 3: Based on step 2 and the pfd mask from § 1.2.1.1, compute for each HAPS the maximum pfd level produced at the FS station location.

Step 4: Compute the FS antenna gain towards the HAPS based on the following input parameters:

– the elevation angle towards the HAPS from step 2;

– azimuth 0 degrees is taken for the azimuth towards the HAPS;

– FS station antenna pointing azimuth: random variable with a uniform distribution between –180 degrees to 180 degrees;

– FS station antenna pointing elevation: random variable with a normal distribution (median 0.01 and standard deviation 1.5);

– FS maximum antenna gain: random variable with a uniform distribution between 32.6 dBi and 47.4 dBi;

– FS antenna pattern: Recommendation ITU-R F.1245-2.

Step 5: Compute and store the level of aggregate interference in dB(W/MHz) produced by all HAPS at the FS receiver input using the following equation:

$$I_M = 10 * \log_{10} \sum_1^N \left(\frac{\mathrm{pfd}_n + 10 \times \log_{10}\left(\frac{\lambda^2}{4\pi}\right) + G_{rn}(\theta_n)}{10} \right)$$

where:

n: index of the HAPS

I_M: aggregate interference level in dB(W/MHz) produced by N HAPS for a certain HAPS configuration M

G_{rn}: FS antenna gain towards the HAPS with the index n

θ_n: angle in degrees between the vector FS → HAPSn and FS antenna main beam pointing vector

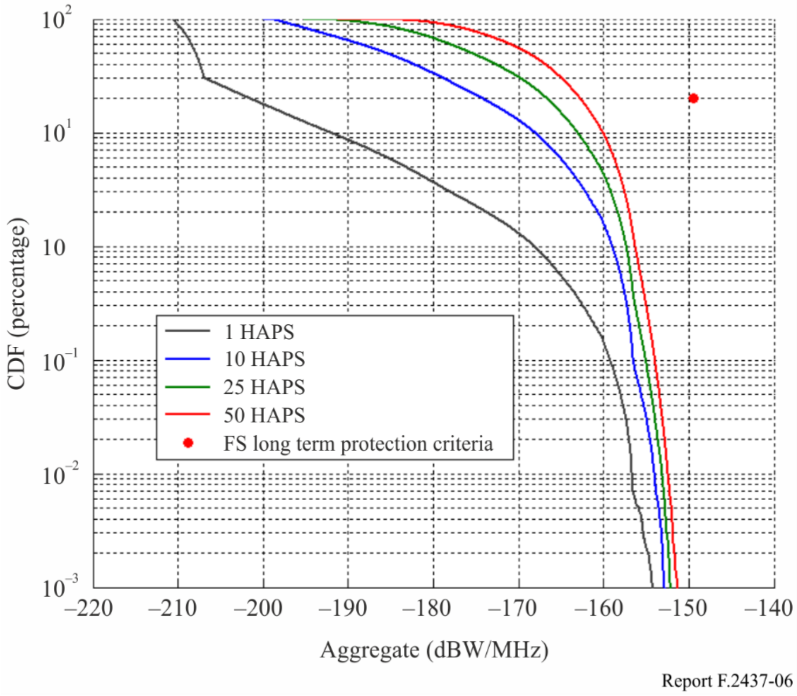
pfd_n: pfd produce at the FS station location by the HAPS with index n (dB(W/(m^2 · MHz))).

Step 6: Redo step 1 to 5 sufficiently to obtain a stable I cumulative distribution function curve and store it.

As it is assumed that no more than 50 HAPS will be in the FS visibility area, the following Figure provides the results with the number of HAPS ranging from 1 to 50.

FIGURE 6

I aggregate in dB(W/MHz)

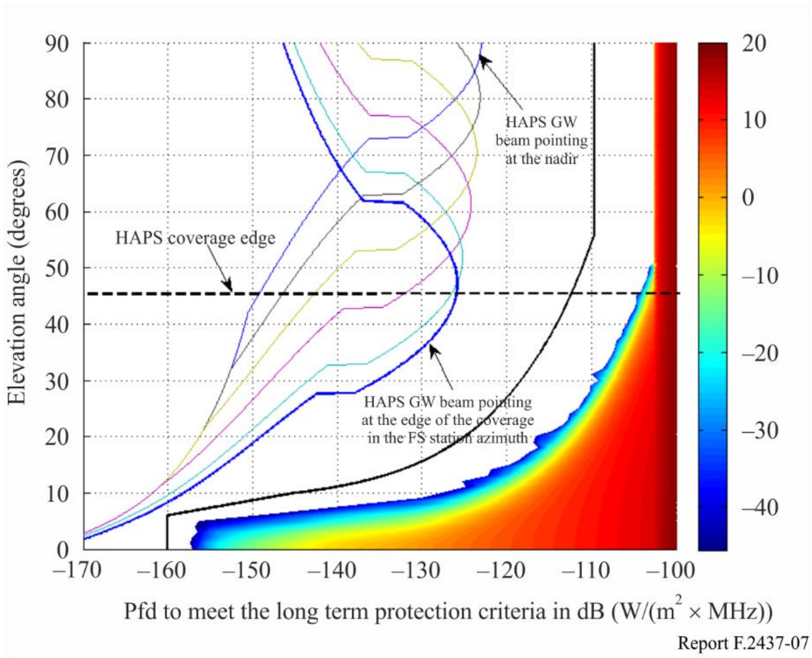


For 1, 10, 25 and 50 HAPS in the FS visibility area, the long-term protection criteria is never exceeded.

Step 7: Comparison of the pfd mask with System 1 maximum pfd level versus elevation is shown in Fig. 7 below and shows that the pfd of a HAPS system designed according to the technical characteristics of system 1 meets the proposed pfd mask. As shown in the Figure below, the pfd produced by System 1 is determined for multiple configurations of the HAPS beam elevation angle, while the azimuth angle is assumed to be directly towards the FS station. These calculations therefore show that it is possible to design a HAPS system that meets the proposed pfd mask and protect FS receivers.

FIGURE 7

HAPS System 1 compliance with the proposed pfd mask



1.2.1.3 Result conclusions

The results in Fig. 7 above are conservative since all HAPS in the visibility area of the FS station will not produce pfd levels exactly at the maximum of the single HAPS pfd mask. Most of them will produce pfd levels which are substantially lower than the pfd in Fig. 7 as they do not all point in the azimuth towards the FS station. Therefore, it can be concluded that the proposed pfd mask also protects FS stations receivers from aggregate HAPS transmissions.

-160	for	$0° \le \theta < 6°$
$3.75\theta - 182.5$	for	$6° \le \theta < 10°$
$-152.5 + 25.5 \log(\theta\text{-}8)$	for	$10° \le \theta < 56°$
-109.63	for	$56° \le \theta \le 90°$

where θ is the angles of arrival of the incident wave above the horizontal plane, in degree.

1.2.2 Impact from transmitting FS stations into HAPS receiving ground station

1.2.2.1 Impact from transmitting FS station into HAPS receiving ground station

The following steps have been performed to derive the minimum separation distance CDF between a single FS station (interferer) and HAPS ground (victim).

Step 1: Compute the FS antenna gain towards the HAPS ground station based on the following input parameters:

– 0° is taken for the elevation angle towards the HAPS;

– 0° is taken for the azimuth towards the HAPS;

– FS station antenna pointing azimuth: random variable with a uniform distribution between –180° to 180°;

– FS station antenna pointing elevation: random variable with a normal distribution (median 0.01 and standard deviation 1.5);

– FS maximum antenna gain (from Recommendation ITU-R F 1245-2): random variable with a uniform distribution between 32.6 dBi and 47.4 dBi;

– FS antenna pattern: Recommendation ITU-R F.1245-2.

Step 2: Compute the HAPS ground station antenna gain towards the FS based on the following input parameters:

– 0 degrees is taken for the elevation angle towards the FS;

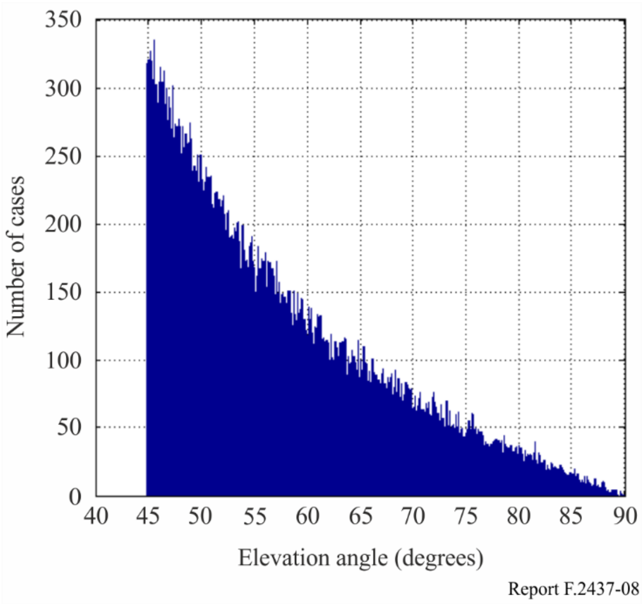
– 180 degrees is taken for the azimuth towards the FS;

– HAPS station antenna pointing azimuth: random variable with a uniform distribution between –180 degrees to 180 degrees;

– HAPS station antenna pointing elevation: random variable with a distribution between 45 and 90 degrees that is shown in Fig. 8.

FIGURE 8

HAPS ground station main beam elevation distribution



– HAPS ground station maximum antenna gain (from system 1 characteristics): 28.8 dBi.

Step 3: Compute the propagation loss needed to meet the HAPS protection criteria:

$$I_{max} = e.i.r.p._{maxFS} - G_{max_{FS}} + G_{FS\rightarrow HAPS_{GS}} - Att_{P-452-16} + Gr_{HAPS}$$

$$Att_{P-452-16} = e.i.r.p._{maxFS} - G_{max_{FS}} + G_{FS\rightarrow HAPS_{GS}} + Gr_{HAPS} - I_{max}$$

where:

$e.i.r.p._{maxFS}$: FS station maximum e.i.r.p. (in the main beam): 24.2 dB(W/MHz)

G_{maxFS}: maximum FS station antenna gain: random variable with a uniform distribution between 32.6 dBi and 47.4 dBi

$G_{FS\rightarrow HAPSGS}$: FS station antenna gain towards the HAPS ground station in dBi (see step 1)

Gr_{HAPS}: HAPS ground station antenna gain towards the FS station in dBi (see step 2)

I_{max}: maximum allowable interference level: for HAPS system 1, −151.6 dB(W/MHz) (*I*/*N* of –10 dB) that should not be exceeded by more than 20% of the time and -131.6 dB(W/MHz) (*I*/*N* of 10 dB) that should not be exceeded by more than 0.01% of the time

$Att_{P\text{-}452\text{-}16}$: propagation loss needed to meet the HAPS protection criteria in dB based on Recommendation ITU-R P.452-16 propagation model with $P = 20\%$ when $I_{max}/N = -10$ dB and $P = 0.01\%$ when $I_{max}/N = 10$ dB. The land path type is used, the typical temperature is taken at 20 degrees, the pressure at 1013 mbar and no clutter.

Step 4: Compute the separation distance needed to meet the HAPS protection criteria based on the propagation model from Recommendation ITU-R P.452.

Step 5: Store the calculated separation distance and repeat steps 1 through 4 sufficiently to obtain a stable CDF.

1.2.2.2 Impact from transmitting FS station into FS receiving station

The following steps have been performed to derive the minimum separation distance CDF between a single FS station (interferer) and FS ground (victim).

Step 1: Compute the FS transmitted station antenna gain towards the FS impacted station based on the following input parameters:

– 0° is taken for the elevation angle towards the HAPS;

– 0° is taken for the azimuth towards the HAPS;

– FS station antenna pointing azimuth: random variable with a uniform distribution between –180° to 180°;

– FS station antenna pointing elevation: random variable with a normal distribution (median 0.01 and standard deviation 1.5);

– FS maximum antenna gain (from Recommendation ITU-R F.1245-2): random variable with a uniform distribution between 32.6 dBi and 47.4 dBi;

– FS antenna pattern: Recommendation ITU-R F.1245.

Step 2: Compute the FS impacted station antenna gain towards the FS transmitted station based on the following input parameters:

– 0° is taken for the elevation angle towards the HAPS;

– 0° is taken for the azimuth towards the HAPS;

– FS station antenna pointing azimuth: random variable with a uniform distribution between –180° to 180°;

– FS station antenna pointing elevation: random variable with a normal distribution (median 0.01 and standard deviation 1.5);

– FS maximum antenna gain (from Recommendation ITU-R F.1245-2): random variable with a uniform distribution between 32.6 dBi and 47.4 dBi;

– FS antenna pattern: Recommendation ITU-R F.1245-2.

Step 3: Compute the propagation loss needed to meet the HAPS protection criteria:

$$I_{max} = e.i.r.p._{maxFS} - G_{max_{FS}} + G_{FS\to FS} - Att_{P-452-16} + Gr_{FS}$$

$$Att_{P-452-16} = e.i.r.p._{maxFS} - G_{max_{FS}} + G_{FS\to FS} + Gr_{FS} - I_{max}$$

where:

$e.i.r.p._{maxFS}$: FS station maximum e.i.r.p. (in the main beam):24.2 dB(W/MHz)

G_{maxFS}: maximum FS station antenna gain: random variable with a uniform distribution between 32.6 dBi and 47.4 dBi

$G_{FS\to FS}$: FS transmitted station antenna gain towards the FS impacted station in dBi

Gr_{FS} : FS impacted station antenna gain towards the FS transmitted station in dBi

$Att_{P\text{-}452\text{-}16}$: propagation loss needed to meet the HAPS protection criteria in dB based on Recommendation ITU-R P.452-16 propagation model with $P = 20\%$ when $I_{max}/N = -10$ dB and $P = 0.01\%$ when $I_{max}/N = 10$ dB. The land path type is used, the typical temperature is taken at 20°, the pressure at 1013 mbar and no clutter

I_{max} : maximum allowable interference level: –149.5 dB(W/MHz) (*I*/*N* of –10 dB) that should not be exceeded by more than 20% of the time and –129.5 dB(W/MHz) (*I*/*N* of 10 dB) that should not be exceeded by more than 0.01% of the time.

Step 4: Compute the separation distance needed to meet the FS protection criteria based on the propagation model from Recommendation ITU-R P.452.

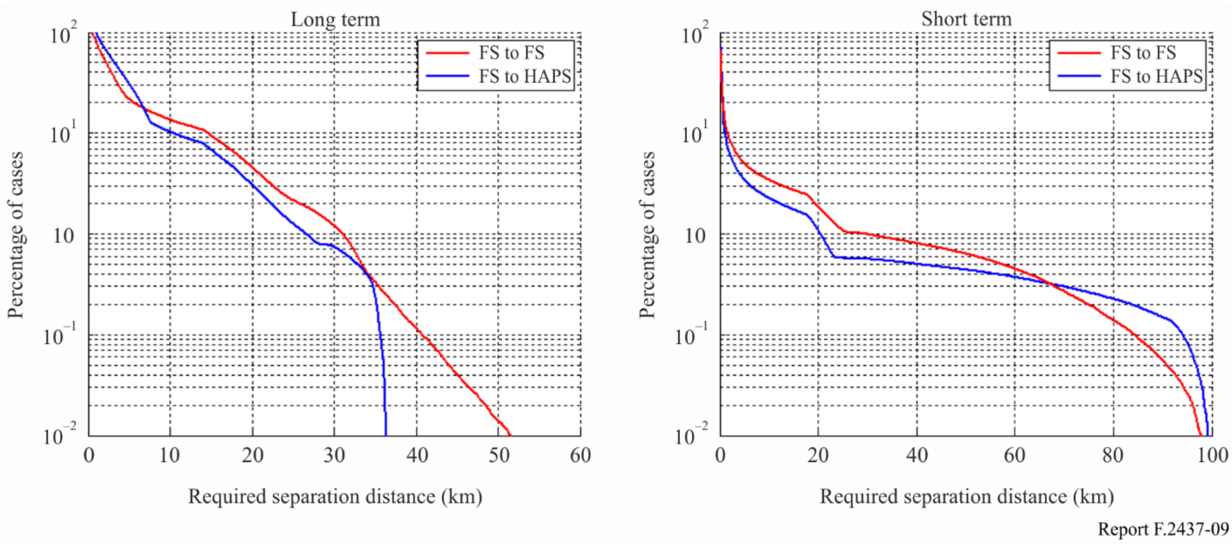
Step 5: Store the calculated separation distance and repeat steps 1 through 4 sufficiently to obtain a stable CDF.

1.2.2.3 Results

Figure 9 provide results for respectively the long term and short-term protection criteria.

FIGURE 9

Required separation distances distribution



From the above results it can be concluded that HAPS ground stations can be considered as any FS station as the result of the impact of FS station emissions into HAPS ground station receivers is less or equivalent than the impact of an FS emitting station into another FS receiving station.

2 Summary and analysis of the results of studies

2.1 Impact from transmitting HAPS s into FS receiving stations

Several studies have shown that the following pfd mask in dB(W/(m^2 · MHz)), to be applied under clear sky conditions at the surface of the Earth, ensures the protection of the Fixed Service by meeting its long-term protection criteria:

–160	for	0° ≤ θ < 6°
3.75θ – 182.5	for	6° ≤ θ < 10°
–152.5 + 25.5 log(θ-8)	for	10° ≤ θ < 56°
–109.63	for	56° ≤ θ ≤ 90°

where θ is the angles of arrival of the incident wave above the horizontal plane, in degree.

Note that the pfd level shown above is derived from a maximum interference level of −149.5 dB(W/MHz) (i.e. *I*/*N* = –10 dB not to be exceeded for more than 20% of the time) for the FS long-term protection criteria. The FS parameters and deployment density are taken from Recommendations ITU-R F.758 and ITU-R F.2086, respectively. Gaseous atmospheric attenuation is not considered for this frequency range.

To verify that the pfd produced by HAPS does not exceed the proposed pfd mask, the following equation was used:

$$pfd(\theta) = e.i.r.p._{\mathrm{dB}\left(\frac{\mathrm{W}}{\mathrm{MHz}}\right)}(\theta) + 10 * log_{10}\left(\frac{1}{4\pi d^2{}_{(\theta)}}\right)$$

where:

e.i.r.p.: maximum HAPS e.i.r.p. density level in dB(W/MHz) (dependent to the elevation angle θ)

d : distance between the HAPS and the ground (elevation angle dependent).

Note that this study did not consider the 6 560-6 640 MHz frequency range.

2.2 Impact from transmitting FS stations into HAPS receiving ground stations

The studies show that the antennas used for both HAPS ground terminals and FS stations are directional, therefore, the required separation distance between the two systems can be reduced by appropriate site-configuration. Protection between HAPS ground stations and conventional FS stations can be managed on a case-by-case basis by coordination amongst administrations or usual link/planning method and procedures used at national level for conventional FS stations.

Annex 2
(FSS (Earth-to-space))

Sharing and compatibility of fixed satellite service (Earth-to-space) and HAPS systems operating in the 6 440-6 520 MHz frequency range

1 Technical Analysis

TABLE 9

Scenario considered

HAPS to FSS satellite receiver	X
FSS Earth station to HAPS ground station	X

1.1 Summary

The first study aims to define the maximum e.i.r.p. level from HAPS versus elevation angle in order to protect FSS space stations receivers. The second study considers the impact from FSS Earth station emissions into HAPS ground station receivers has also been performed. The second study was presented for the purpose of showing whether HAPS can co-exist with FSS.

1.2 Analysis

1.2.1 Impact from transmitting HAPS into FSS receiving space station

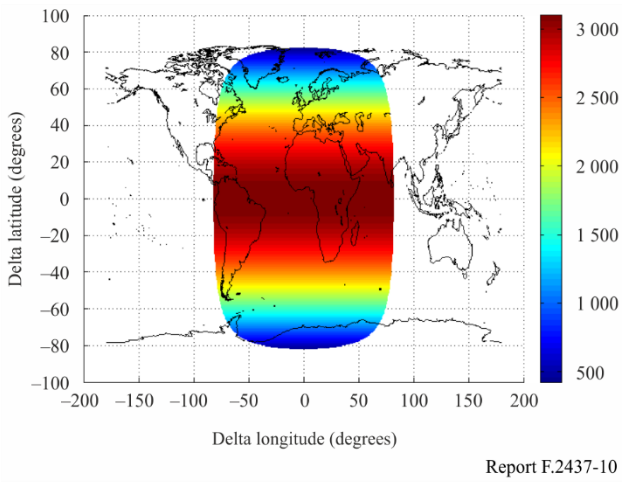
The following steps have been performed to derive an HAPS maximum e.i.r.p. toward FSS satellite receivers taken into account the HAPS aggregate impact.

Step 1: A land grid map is created with a step of 0.5 degrees in longitude and 0.5 degrees in latitude, resulting in dividing the map into elementary surfaces *Nc*: 0.5°× 0.5° cells within the satellite visibility area. In the analysis, the satellite is located at a longitude of 0 degrees. The analysis results can however be extrapolated to any satellite location longitude.

Step 2: A grid of *Nc* elementary surfaces is created in the area of the Earth visible to the satellite. The elementary surface is defined by a step of 0.5 degrees in longitude and latitude and is expressed in km^2.

FIGURE 10

Elementary surface in km^2



Step 4: A grid of the number of HAPS (N_{HAPS}) transmitting simultaneously in an elementary surface *n* (see step 2) is created. N_{HAPSn} is defined as follows:

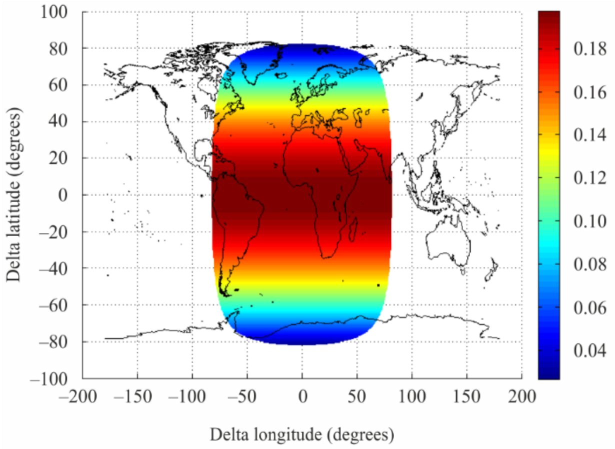
$$N_{HAPS} = Sn \cdot D_{HAPS}$$

with:

- n : index of step 2 grid (elementary surface grid map)
- S_n : elementary surface from step 2 (km^2)
- D_{HAPS} : HAPS density. A maximum of 50 HAPS is considered visible from any point of the Earth with an elevation angle higher than 0 degree. This gives a HAPS density of 6.37e-5 HAPS per km^2; and represents around 41 HAPS over a territory having the same surface than France.

FIGURE 11

Number of HAPS per elementary surface



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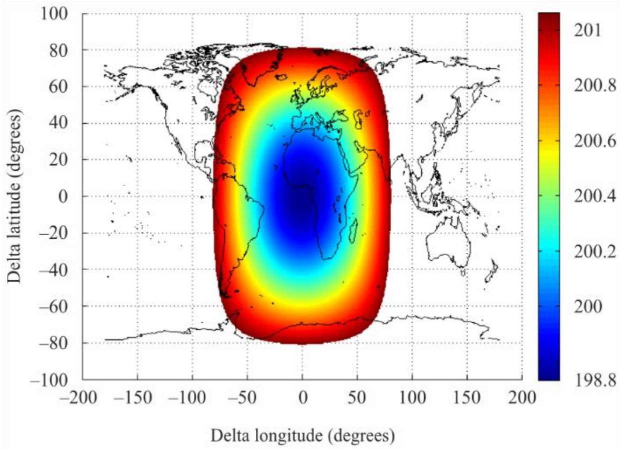
Step 5: Attenuation due to propagation.

Free Space Loss between the HAPS and the satellite (Recommendation ITU-R P.525).

FIGURE 12

Free space loss in dB



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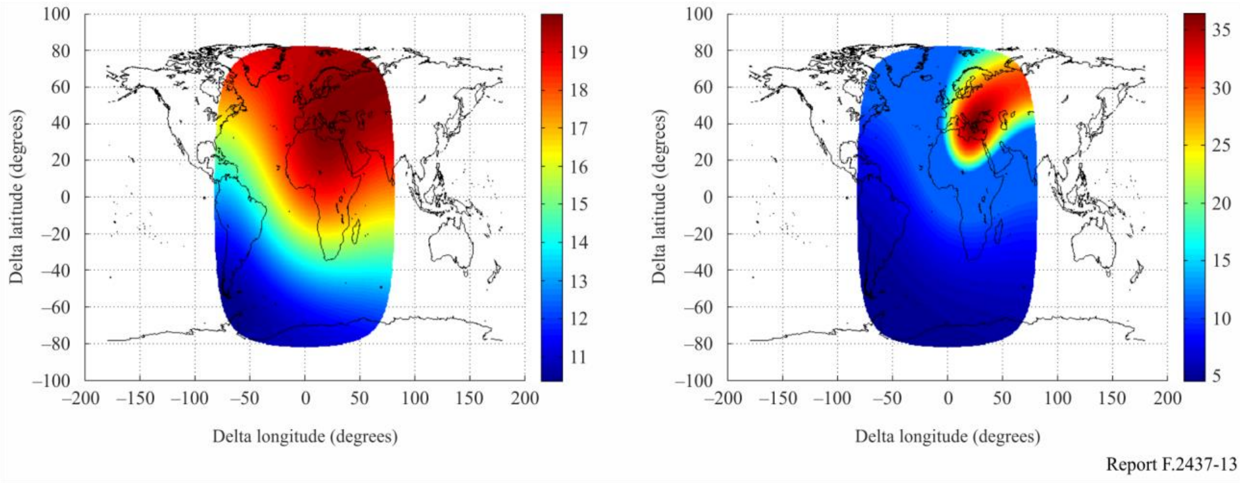
Step 6: Set the pointing direction of the satellite beam towards the ground with a minimum elevation angle of 5 degrees. Compute the satellite beam antenna gain towards each point of the grid from step 2. As an example, Fig. 13 provides the results for respectively an FSS antenna Gain of 20 dBi (carrier 11) and 36.4 dBi (carrier 12) and a pointing direction toward a point located at the Earth surface with a longitude of 25 degrees and a latitude of 40 degrees.

FIGURE 13

FSS satellite receiver antenna gain (carrier 11 left and carrier 12 right) when pointing toward 25 degrees longitude and 40 degrees latitude



Step 7: The interference received by the satellite from each cell of step 2 is computed.

The interference from the HAPS towards a satellite receiver can be expressed as:

$$I_n = e.i.r.p. + 10 * log_{10}(N_{HAPSn}) - FSL_n + Gr_n$$

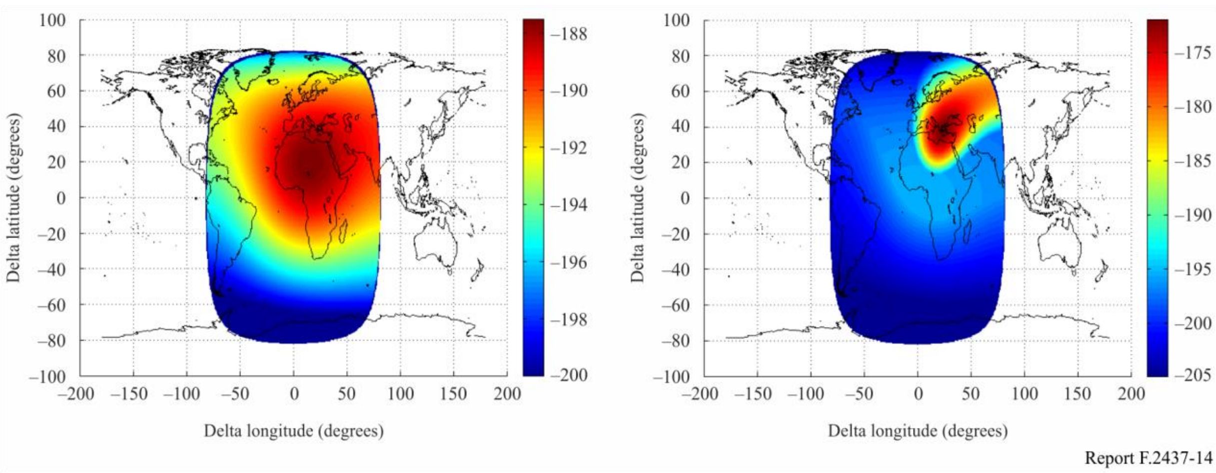
where:

- n : index of step 2 grid (elementary surface grid map)
- N_{HAPSn} : number of HAPS in cell number n
- *e.i.r.p.*: maximum HAPS e.i.r.p. for elevation angle higher than 5° (0 dB(W/MHz) is used for the analysis)
- Gr_n : FSS satellite receiver antenna gain towards cell number n
- FSL_n : is the free space loss in dB between the FSS satellite and the cell n (see step 5 results).

As an example, Fig. 14 provides the interference produced by each cells in the case of for respectively an FSS antenna Gain of 20 dBi (carrier 11) and 36.4 dBi (carrier 12) and a pointing direction toward a point located at the Earth surface with a longitude of 25 degrees and a latitude of 40 degrees.

FIGURE 14

Received interference from each elementary surface (carrier 11 left and carrier 12 right) when pointing toward 25 degrees longitude and 40 degrees latitude



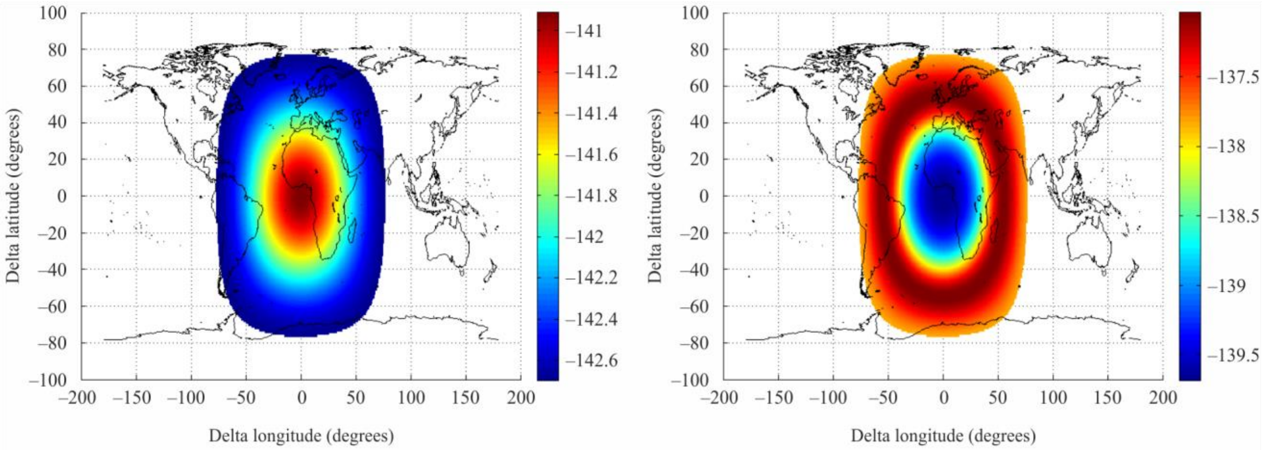
Step 8: The aggregate interference received by the satellite from all cells of step 2 is computed and stored. The interference from the HAPS towards a satellite receiver can be expressed as:

$$I_{agg} = 10 * log_{10}\left(\sum_{1}^{N_C} 10^{\left(\frac{I_n}{10}\right)}\right)$$

Step 9: Redo step 6, 7 and 8 for any possible satellite pointing direction (1 degree step for longitude and latitude and with a minimum elevation angle of 5 degrees). Figure 15 shows the final result. It represents the aggregate interference received by the satellite receiver from all HAPS versus satellite beam pointing direction. It should be noted that this analysis is a worst case as it is assumed that HAPS are also located over the ocean.

FIGURE 15

Received aggregate interference (carrier 11 left and carrier 12 right)



NOTE – The delta longitude/delta latitude represents the pointing direction of the FSS receiver beam and the colour provides the level of aggregate interference.

The maximum impact corresponds to an FSS receiver antenna gain of 36.4 dBi (carrier 12) and is equal to –137 dB(W/MHz). Therefore with an e.i.r.p. of 0 dB(W/MHz) per HAPS the worst case aggregate impact is 17.8 dB higher than the FSS protection criteria (–153.1 dB(W/MHz)). Therefore the e.i.r.p. per HAPS transmitter should be limited to –16.1 dB(W/MHz) for elevation angle higher than 5 degrees in order to protect FSS receivers. System 1 maximum e.i.r.p. above 5 degrees elevation is –46.4 dB(W/MHz) and therefore it is possible to design a HAPS system compliance with the above propose e.i.r.p. limit and protect FSS satellite with large margin.

1.2.2 Impact from transmitting FSS Earth station into HAPS receiving ground station

1.2.2.1 Impact from transmitting FSS Earth station into HAPS receiving ground station

The following steps have been performed to derive the minimum separation distance CDF between a single FSS Earth station (interferer) and HAPS ground (victim).

Step 1: Compute the FSS Earth station antenna gain towards the HAPS ground station based on the following input parameters:

– 0 degree is taken for the elevation angle towards the HAPS;
– 0 degree is taken for the azimuth towards the HAPS;
– FSS station antenna pointing azimuth: random variable with a uniform distribution between –180 degrees to 180 degrees;
– FSS station antenna pointing elevation: 5 degrees (worst case);

– FSS maximum antenna gain: 39.9 dBi and 57.2 dBi;

– FSS antenna pattern: Recommendation ITU-R S.465-6.

Step 2: Compute the HAPS ground station antenna gain towards the FSS Earth station based on the following input parameters:

– 0 degree is taken for the elevation angle towards the FS;

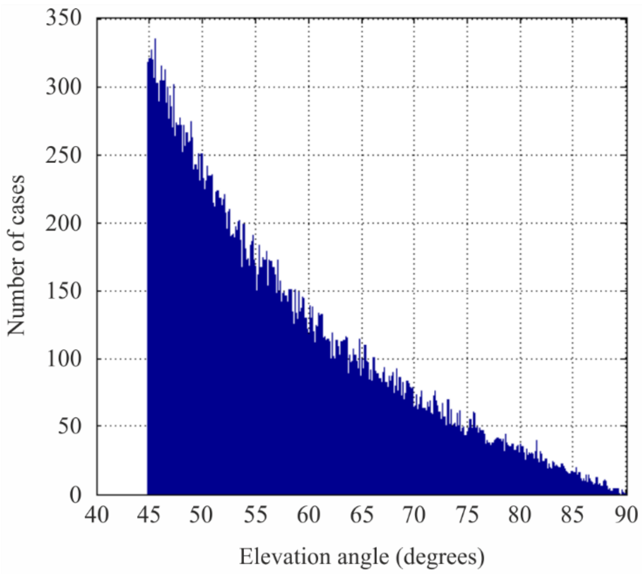
– 180 degrees is taken for the azimuth towards the FS;

– HAPS ground station antenna pointing azimuth: random variable with a uniform distribution between –180 degrees to 180 degrees;

– HAPS station antenna pointing elevation: random variable with a distribution between 45 and 90 degrees that is shown in Fig. 16.

FIGURE 16

HAPS ground station main beam elevation distribution



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– HAPS ground station maximum antenna gain (from System 1 characteristics): 28.8 dBi.

Step 3: Compute the propagation loss needed to meet the HAPS protection criteria:

$$I_{max} = e.i.r.p._{maxFSS_{ES}} - G_{maxFSS_{ES}} + G_{FSS_{ES}\rightarrow HAPS_{GS}} - Att_{P-452-16} + Gr_{HAPS_{GS}}$$

$$Att_{P-452-16} = e.i.r.p._{maxFSS_{ES}} - G_{maxFSS_{ES}} + G_{FSS_{ES}\rightarrow HAPS_{GS}} + Gr_{HAPS_{GS}} - I_{max}$$

where:

$e.i.r.p._{maxFSSES}$: FSS Earth station maximum e.i.r.p. (in the main beam): 10 dB(W/MHz) (carrier 11) and 27 dB(W/MHz) (carrier 12)

$G_{maxFSSES}$: maximum FSS Earth station antenna gain: random variable with a uniform distribution between 39.9 dBi (carrier 11) and 57.2 dBi (carrier 12)

$G_{FSSES\rightarrow HAPSGS}$: FSS Earth station antenna gain towards the HAPS ground station in dBi (see step 1)

Gr_{HAPSGS}: HAPS ground station antenna gain towards the FSS station in dBi (see step 2);

I_{max} : maximum allowable interference level: for HAPS system 1, −151.6 dB(W/MHz) (I/N of –10 dB) that should not be exceeded by more than 20% of the time and –131.6 dB(W/MHz) (I/N of 10 dB) that should not be exceeded by more than 0.01% of the time

$Att_{P\text{-}452\text{-}16}$: is the propagation loss needed to meet the HAPS protection criteria in dB based on Recommendation ITU-R P.452-16 propagation model with P = 20% when I_{max}/N = –10 dB and P = 0.01% when I_{max}/N = 10 dB. The land path type is used, the typical temperature is taken at 20°, the pressure at 1013 mbar and no clutter.

Step 4: Compute the separation distance needed to meet the HAPS protection criteria based on the propagation model from Recommendation ITU-R P.452.

Step 5: Store the calculated separation distance and repeat steps 1 through 4 sufficiently to obtain a stable CDF.

1.2.2.2 Impact from transmitting FSS Earth station into FS receiving ground stations

The following steps have been performed to derive the minimum separation distance CDF between a single FSS Earth station (interferer) and FS ground (victim).

Step 1: Compute the FSS Earth station antenna gain towards the FS station based on the following input parameters:

– 0° is taken for the elevation angle towards the FS;

– 0° is taken for the azimuth towards the FS;

– FSS station antenna pointing azimuth: random variable with a uniform distribution between –180° to 180°;

– FSS station antenna pointing elevation: 5 degrees (worst case);

– FSS maximum antenna gain: 39.9 dBi and 57.2 dBi;

– FSS antenna pattern: Recommendation ITU-R S.465-6.

Step 2: Compute the FS impacted station antenna gain towards the FSS transmitted Earth station based on the following input parameters:

– 0° is taken for the elevation angle towards the FSS;

– 180° is taken for the azimuth towards the FSS;

– FS station antenna pointing azimuth: random variable with a uniform distribution between –180° to 180°;

– FS station antenna pointing elevation: random variable with a normal distribution (median 0.01 and standard deviation 1.5);

– FS maximum antenna gain (from Recommendation ITU-R F.1245-2): random variable with a uniform distribution between 32.6 dBi and 47.4 dBi;

– FS antenna pattern: Recommendation ITU-R F.1245-2.

Step 3: Compute the propagation loss needed to meet the FS protection criteria:

$$I_{max} = e.i.r.p._{maxFSS_{ES}} - G_{max_{FSS_{ES}}} + G_{FSS_{ES}\to FS} - Att_{P-452-16} + Gr_{FS}$$

$$Att_{P-452-16} = e.i.r.p._{maxFSS_{ES}} - G_{max_{FSS_{ES}}} + G_{FSS_{ES}\to FS} + Gr_{FS} - I_{max}$$

where:

$e.i.r.p._{maxFSSES}$: FSS Earth station maximum e.i.r.p. (in the main beam): 10 dB(W/MHz) (carrier 11) and 27 dB(W/MHz) (carrier 12)

$G_{maxFSSES}$: maximum FSS Earth station antenna gain: random variable with a uniform distribution between 39.9 dBi (carrier 11) and 57.2 dBi (carrier 12)

$G_{FSSES \rightarrow FS}$: FSS Earth station antenna gain towards the FS station in dBi (see step 1)

Gr_{FS} : FS impacted station antenna gain towards the FSS transmitted Earth station in dBi

$Att_{P\text{-}452\text{-}16}$: propagation loss needed to meet the HAPS protection criteria in dB based on Recommendation ITU-R P.452-16 propagation model with $P = 20\%$ when $I_{max}/N = –10$ dB and $P = 0.01\%$ when $I_{max}/N = 10$ dB. The land path type is used, the typical temperature is taken at 20°, the pressure at 1013 mbar and no clutter

I_{max} : maximum allowable interference level: –149.5 dB(W/MHz) (I/N of -10 dB) that should not be exceeded by more than 20% of the time and –129.5 dB(W/MHz) (I/N of 10 dB) that should not be exceeded by more than 0.01% of the time.

Step 4: Compute the separation distance needed to meet the FS protection criteria based on the propagation model from Recommendation ITU-R P.452.

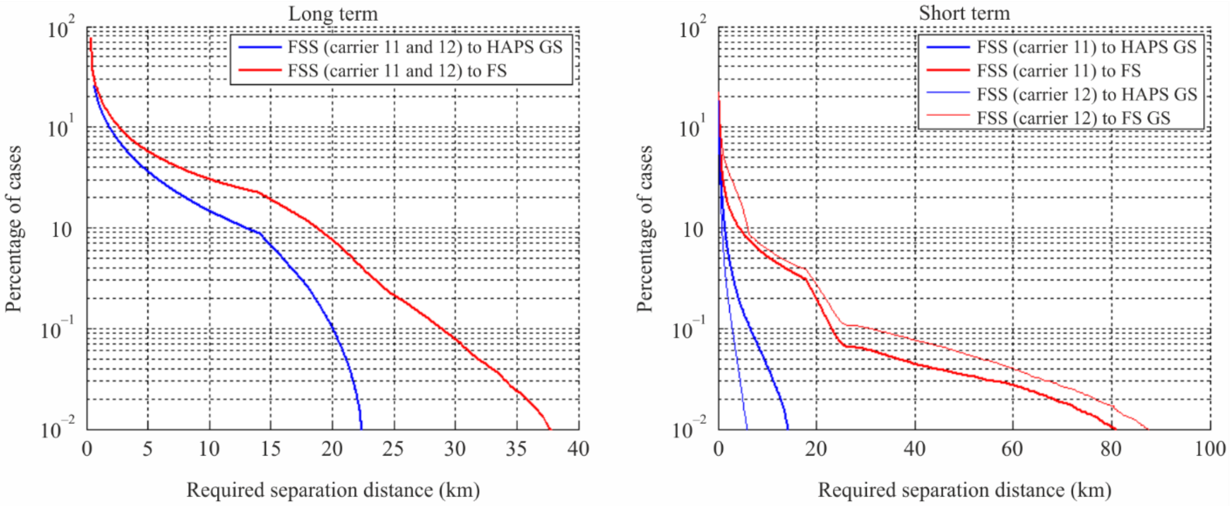
Step 5: Store the calculated separation distance and repeat steps 1 through 4 sufficiently to obtain a stable CDF.

1.2.2.3 Results

Figure 17 provides results for respectively the long term and short-term protection criteria.

FIGURE 17

Required separation distances distribution



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From the above results it can be concluded that HAPS ground stations can be considered as any FS station as the result of the impact of FSS station emissions into HAPS ground station receivers is less than the impact of an FSS emitting station into an FS receiving station.

2 Summary and analysis of the results of studies

2.1 Impact from transmitting HAPS into FSS receiving space station

This study shows that, in order to protect FSS space station receivers, the e.i.r.p. per HAPS transmitter should be limited to –17.8 dB(W/MHz) towards the GSO arc.[2] The study also shows that it is possible to design a HAPS system compliant with the above proposed e.i.r.p. limit and protect FSS satellite with large margin.

2.2 Impact from transmitting FSS Earth station into HAPS receiving ground stations

This study considered the potential emissions from FSS Earth stations received by the HAPS ground stations receivers. This analysis also compared the level of emissions at the HAPS receivers to those that would be received by a fixed service receiver.

The analysis performed shows that the required separation distance of HAPS ground stations receivers and FSS Earth stations is less than the required separation distance between an FSS Earth station and FS terminal.

Annex 3
(MS)

Sharing and compatibility of MS and HAPS systems operating in the 6 440-6 520 MHz frequency range

1 Technical Analysis

TABLE 10

Scenario considered

HAPS to MS	X
MS to HAPS ground station	X

TABLE 11

Attenuation/assumption considered in the study

	HAPS to MS	MS to HAPS ground station
Polarisation loss	0 dB	0 dB
Body loss (UE)	0 dB	0 dB
Gaseous attenuation	None (Negligible)	Yes (P.452)
Propagation model	Rec. ITU-R P.525 (FSL)	Rec. ITU-R P.452
Clutter loss	None	None
Apportionment	None	NA
Aggregate HAPS consideration	Yes (from 1 to 50 HAPS)	No (single-entry, statistical)
HAPS system	System 1	System 1

[2] Based on a uniform density of HAPS of 6.37e-5 HAPS/km^2, which equates to approximately 41 HAPS in an area the size of France.

1.1 Summary

This study aims to define the maximum pfd level from HAPS versus elevation angle in order to protect MS stations receivers.

1.2 Analysis

1.2.1 Impact from transmitting HAPS into MS receiving stations

The maximum pfd level per HAPS is computed using the following equation and depends on the number of HAPS in the MS visibility area.

$$pfd_{max} = I_{max} + 10 \times \log_{10}\left(\frac{4\pi}{\lambda^2}\right) - G_r(\theta) - 10 * log10(N)$$

where:

I_{max} : maximum interference level

G_r : MS antenna gain towards the HAPS

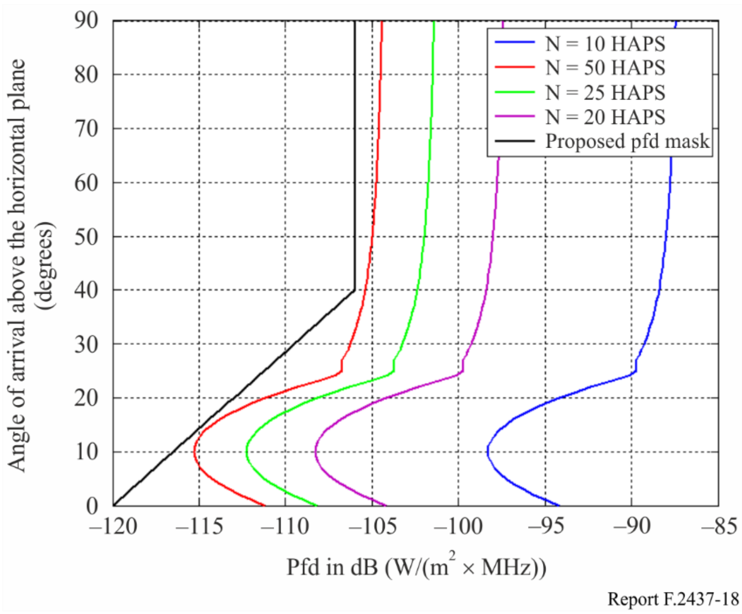
θ : angle between the vector MS → HAPS and MS antenna main beam pointing vector.

Note that gaseous atmospheric loss was not considered for this frequency range as it is negligible.

As it is assumed that no more than 50 HAPS will be in the MS visibility area, the following figure provides the results for different number of HAPS from 1 to 50 as well as the proposed pfd mask to protect MS.

FIGURE 18

Proposed pfd mask versus elevation angle



According to the results above, HAPS technology can coexist with incumbent MS in the 6 GHz band in case the pfd level produced at the Earth surface is below the following proposed pfd mask.

0.35 θ – 120	for	0° ≤ θ < 40°
–106	for	40° ≤ θ ≤ 90°

where θ is the angles of arrival of the incident wave above the horizontal plane, in degree. It should be noted that the propose pfd mask to protect MS is less constraining than the pfd mask to protect FS. Therefore, HAPS system 1 is also compliance with the proposed pfd mask to protect MS.

1.2.2 Impact from transmitting MS station into HAPS receiving ground stations

1.2.2.1 Impact from transmitting MS station into HAPS receiving ground stations

The following steps have been performed to derive the minimum separation distance CDF between a single MS station (interferer) and HAPS ground (victim).

Step 1: Compute the MS antenna gain towards the HAPS ground station based on the following input parameters:

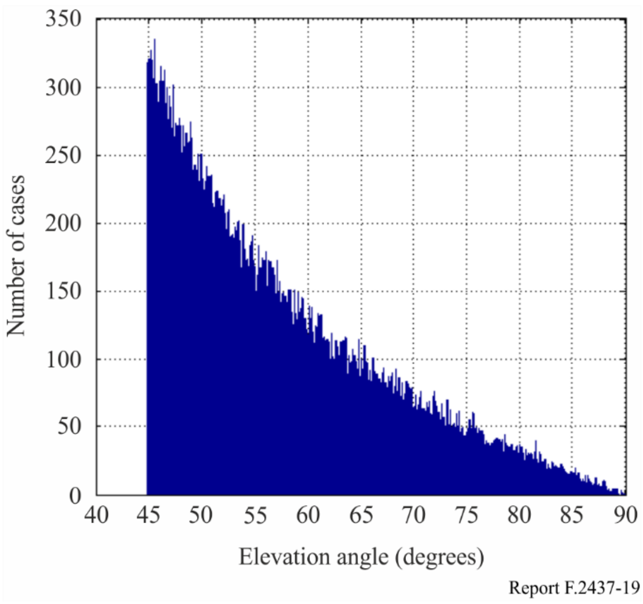
– 0° is taken for the elevation angle towards the HAPS;
– 0° is taken for the azimuth towards the HAPS;
– MS station antenna pointing azimuth: random variable with a uniform distribution between –180° to 180°;
– MS station antenna pointing elevation: random variable with a uniform distribution between 0 and 10°;
– MS maximum antenna gain: 8 dBi;
– MS antenna pattern: Recommendation ITU-R F.1336-2.

Step 2: Compute the HAPS ground station antenna gain towards the MS based on the following input parameters:

– 0° is taken for the elevation angle towards the MS;
– 180° is taken for the azimuth towards the MS;
– HAPS station antenna pointing azimuth: random variable with a uniform distribution between –180° to 180°;
– HAPS station antenna pointing elevation: random variable with a distribution between 45 and 90 degrees that is shown in Fig. 19.

FIGURE 19

HAPS ground station main beam elevation distribution



– HAPS ground station maximum antenna gain (from System 1 characteristics): 28.8 dBi.

Step 3: Compute the propagation loss needed to meet the HAPS protection criteria:

$$I_{max} = e.i.r.p._{maxMS} - G_{max_{MS}} + G_{MS\rightarrow HAPS_{GS}} - Att_{P-452-16} + Gr_{HAPS}$$

$$Att_{P-452-16} = e.i.r.p._{maxMS} - G_{max_{MS}} + G_{MS\rightarrow HAPS_{GS}} + Gr_{HAPS} - I_{max}$$

where:

$e.i.r.p._{maxMS}$:	MS station maximum e.i.r.p. (in the main beam): –15 dB(W/MHz)
G_{maxMS} :	maximum MS station antenna gain
$G_{MS\rightarrow HAPSGS}$:	MS station antenna gain towards the HAPS ground station in dBi (see step 1)
Gr_{HAPS} :	HAPS ground station antenna gain towards the MS station in dBi (see step 2)
I_{max} :	maximum allowable interference level: for HAPS system 1, −151.6 dB(W/MHz) (*I*/*N* of –10 dB) that should not be exceeded by more than 20% of the time and –131.6 dB(W/MHz) (*I*/*N* of 10 dB) that should not be exceeded by more than 0.01% of the time
$Att_{P\text{-}452\text{-}16}$:	propagation loss needed to meet the HAPS protection criteria in dB based on Recommendation ITU-R P.452-16 propagation model with $P = 20\%$ when $I_{max}/N = -10$ dB and P=0.01% when $I_{max}/N = 10$ dB. The land path type is used, the typical temperature is taken at 20°, the pressure at 1013 mbar and no clutter.

Step 4: Compute the separation distance needed to meet the HAPS protection criteria based on the propagation model from Recommendation ITU-R P.452.

Step 5: Store the calculated separation distance and repeat steps 1 through 4 sufficiently to obtain a stable CDF.

1.2.2.2 Transmitting MS station impact into FS receiving station

The following steps have been performed to derive the minimum separation distance CDF between a single MS station (interferer) and FS ground (victim).

Step 1: Compute the MS antenna gain towards the FS station based on the following input parameters:

– 0° is taken for the elevation angle towards the FS;

– 0° is taken for the azimuth towards the FS;

– MS station antenna pointing azimuth: random variable with a uniform distribution between –180° to 180°;

– MS station antenna pointing elevation: random variable with a uniform distribution between 0 and 10°;

– MS maximum antenna gain: 8 dBi;

– MS antenna pattern: ITU-R F.1336-2.

Step 2: Compute the FS impacted station antenna gain towards the MS transmitted station based on the following input parameters:

– 0° is taken for the elevation angle towards the MS;

– 0° is taken for the azimuth towards the MS;

– FS station antenna pointing azimuth: random variable with a uniform distribution between –180° to 180°;

– FS station antenna pointing elevation: random variable with a normal distribution (median 0.01 and standard deviation 1.5);
– FS maximum antenna gain (from Recommendation ITU-R F.1245-2): random variable with a uniform distribution between 32.6 dBi and 47.4 dBi;
– FS antenna pattern: Recommendation ITU-R F.1245-2.

Step 3: Compute the propagation loss needed to meet the FS protection criteria:

$$I_{max} = e.i.r.p._{maxMS} - G_{max_{MS}} + G_{MS\rightarrow FS} - Att_{P-452-16} + Gr_{FS}$$

$$Att_{P-452-16} = e.i.r.p._{maxMS} - G_{max_{MS}} + G_{MS\rightarrow FS} + Gr_{FS} - I_{max}$$

where:

$e.i.r.p._{maxMS}$: MS station maximum e.i.r.p. (in the main beam): –15 dB(W/MHz)

G_{maxMS} : maximum MS station antenna gain

$G_{MS\rightarrow FS}$: MS transmitted station antenna gain towards the FS impacted station in dBi

Gr_{FS} : FS impacted station antenna gain towards the FS transmitted station in dBi

$Att_{P\text{-}452\text{-}16}$: is the propagation loss needed to meet the HAPS protection criteria in dB based on Recommendation ITU-R P.452-16 propagation model with P = 20% when I_{max}/N = –10 dB and P = 0.01% when I_{max}/N = 10 dB. The land path type is used, the typical temperature is taken at 20 degrees, the pressure at 1013 mbar and no clutter

I_{max}: the maximum allowable interference level: –149.5 dB(W/MHz) (I/N of −10 dB) that should not be exceeded by more than 20% of the time and −129.5 dB(W/MHz) (I/N of 10 dB) that should not be exceeded by more than 0.01% of the time.

Step 4: Compute the separation distance needed to meet the FS protection criteria based on the propagation model from Recommendation ITU-R P.452.

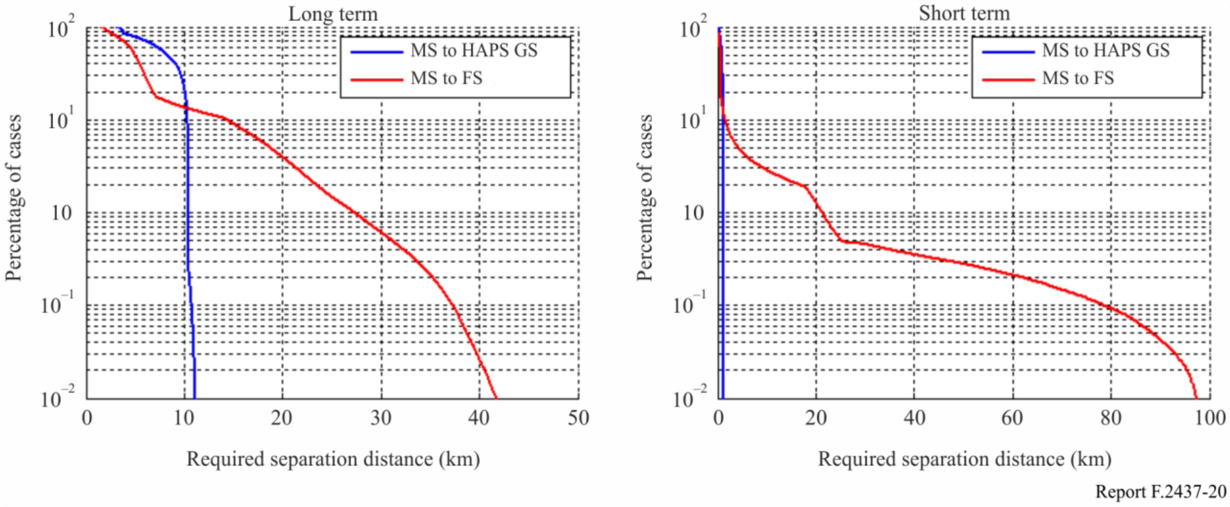
Step 5: Store the calculated separation distance and repeat steps 1 through 4 sufficiently to obtain a stable CDF.

1.2.2.3 Results

Figure 20 provides results for respectively the long term and short term protection criteria.

FIGURE 20

Required separation distances distribution



From the above results, it can be concluded that HAPS ground stations can be considered as any FS station as the result of the impact of MS station emissions into HAPS ground station receivers is less or equivalent than the impact of an MS emitting station into FS receiving station.

2 Summary and analysis of the results of studies

2.1 Impact from transmitting HAPS into MS receiving stations

Several studies have shown that the following pfd mask in dB(W/(m^2 · MHz)) ensures the protection of the Mobile Service receivers from a single HAPS emission:

0.35 θ – 120	for	0° ≤ θ < 40°
–106	for	40° ≤ θ ≤ 90°

where θ is the angles of arrival of the incident wave above the horizontal plane, in degree.

Note that gaseous atmospheric loss was not considered for this frequency range as it is negligible.

To verify that pfd produced by HAPS does not exceed the proposed pfd mask, the following equation was used:

$$pfd(\theta) = e.i.r.p._{\mathrm{dB}(\frac{\mathrm{W}}{\mathrm{MHz}})}(\theta) + 10 * log_{10}\left(\frac{1}{4\pi d^2{}_{(\theta)}}\right)$$

where:

e.i.r.p.: maximum HAPS e.i.r.p. density level in dB(W/MHz) (dependent to the elevation angle)

d : distance between the HAPS and the ground (elevation angle dependent)

θ : angles of arrival of the incident wave above the horizontal plane, in degree.

2.2 Impact from transmitting MS station into HAPS receiving ground stations

One study performed two different percentage of time, i.e., 20% and 0.01%, using propagation model ITU-R P.452. The study showed that for both cases, the impact of MS station emissions into HAPS ground station receivers is in order of 0-10 km depending on the probability considered compared to 0-43 km between the MS and conventional FS station for the same probabilities. In addition, the required separation distance can be further reduced by appropriate site-configuration, due to HAPS antenna directivity. Therefore, protection between HAPS ground stations and MS stations can be managed on a case-by-case basis by coordination amongst administrations at national level.

Annex 4
(EESS (passive))

Sharing and compatibility of EESS (passive) and HAPS systems operating in the 6 440-6 520 MHz frequency range

1 Technical analysis

TABLE 12

Scenario considered

	Study A	Study B
HAPS transmitter to EESS passive receiver	X	X

1.1 Summary

The studies aim to define the maximum HAPS e.i.r.p. level toward any EESS passive satellite receiver versus elevation angle in order to protect EESS passive stations receivers.

1.2 Analysis

1.2.1 Study A

This study addresses compatibility between HAPS downlink towards HAPS ground station in the band 6 440-6 520 MHz and EESS (passive) in the same band.

1.2.1.1 Methodology used

This study uses the multiple-entry calculation from Methodology 1 as described in scenario 4 in Annex 26 to Working Party 5C Chairman's Report.

However, due to the specific applications foreseen in this band, HAPS deployment is limited to a small portion of the measurement area.

The propagation loss is free space plus gaseous attenuation as per Recommendation ITU-R P.676.

1.2.1.2 EESS (passive) parameters used

The protection criterion considered for the EESS (passive) is given in Recommendation ITU-R RS.2017 as a threshold of –166 dB(W/200 MHz) not to be exceeded more than 0.1% of the time over a measurement area of 10 000 000 km^2. No apportionment was considered for this specific case.

The sensor considered is sensor B2 (Conical scan) contained within Recommendation ITU-R RS.1861, which is the only one operating within the same band.

1.2.1.3 HAPS parameters used

This study applies to system 1 which is the only system considering this band in the downlink direction. The HAPS is positioned between 18 and 25 km altitude. Its coverage radius is 50 km. The HAPS have been distributed on a grid each 100 km within a small portion of the measurement area where those specific applications would be needed in case of disaster management for instance, leading to 12 HAPS in total.

The antenna on board the HAPS system is parabolic, following the Recommendation ITU-R F.1245 antenna pattern according to the HAPS characteristics document, with a far sidelobe level of –6 dBi when the maximum gain is 18.4 dBi.

There would be between 0 and 70 degrees offset angle between the HAPS nadir and the direction towards the HAPS ground station, leading to –30 degrees elevation of the HAPS ground station as seen from the HAPS. The EESS sensors operate with elevation angles above 20 degrees, so it is legitimate to consider that the antenna gain towards the EESS sensor would always be –6 dBi.

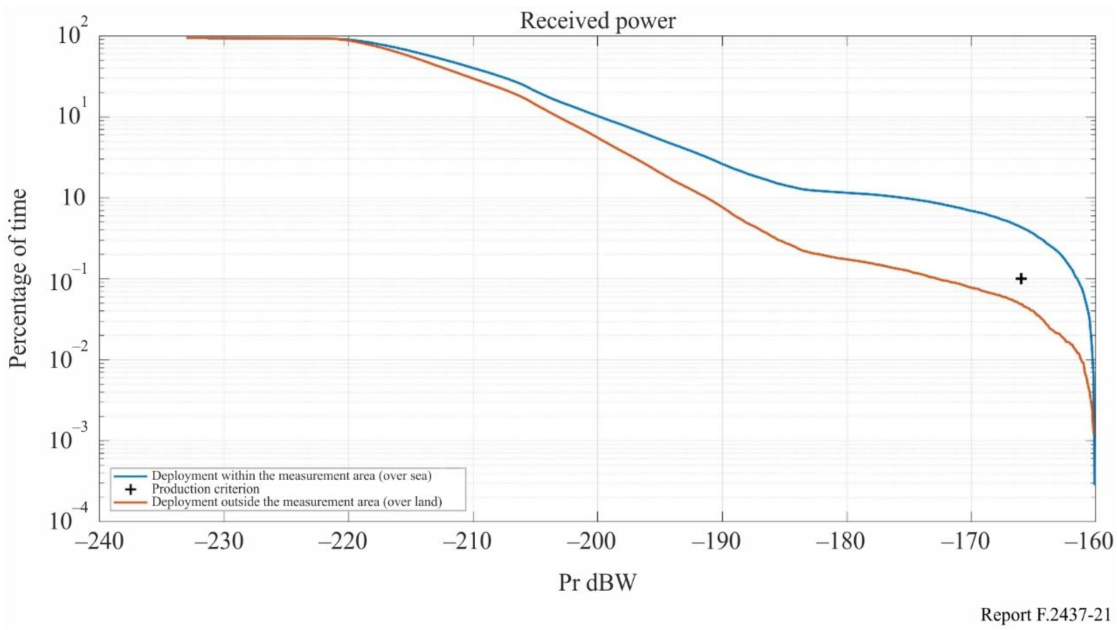
1.2.1.4 Calculation results

The following cumulative distribution functions provide the interference levels produced within the passive band assuming that the unwanted emission power per 200 MHz bandwidth is –24.4 dBW, which is the total in-band emission power for the two polarizations.

The measurement area is over the ocean, since the operation of sensors in this band is according to RR No. **5.458** limited over the oceans. Two HAPS deployments are then considered. In the first one, the 12 HAPS are deployed within the measurement area, which would be the case if HAPS are deployed over the ocean. In the second case, the 12 HAPS are deployed at the edge of the measurement area, which would be the case for instance if the HAPS deployment is limited to land areas.

FIGURE 21

Level of interference from the HAPS



It can be seen that the protection criterion would be exceeded by 4.5 dB if HAPS are deployed over sea, and would be met with 6.7 dB margin if the deployment is limited to land areas.

1.2.1.5 Summary and analysis of the results of Study A

This study shows that in order to protect EESS (passive) measurements within the band 6 440-6 520 MHz in the band 6 440-6 520 MHz from harmful interference, the output power would have to be reduced by 4.5 dB, or, alternatively, the deployment should be limited to land areas.

1.2.2 Study B

1.2.2.1 Interference from one HAPS into EESS (passive) receiver

Methodology and parameters used.

Maximum antenna gain towards the EESS passive receivers is presented in Table 13.

The HAPS beam is pointing toward the HAPS coverage area and therefore EESS passive receivers could receive interference from the sidelobes of the HAPS antenna (–6 dBi). The maximum interference level produced per HAPS into the EESS passive is also provided in Table 13 below:

TABLE 13

EESS Parameters

		Sensor B1	Sensor B2	Sensor B3	Sensor B4	Comments
G_{max} EESS satellite	dBi	38.8	41.1	30.2	40.6	
Maximum HAPS e.i.r.p.	dB(W/200 MHz)	–6				–9 per polarization
G_{max} HAPS	dBi	18.4				Towards HAPS ground coverage 20 km circle radius
G_{max} HAPS towards EESS satellite	dBi	–6				Incident angle at the Earth 55.7°
Maximum HAPS e.i.r.p. towards EESS satellite	dB(W/200 MHz)	–30.4				= –6 – 18.4 – 6
Maximum allowable aggregate I	dB(W/200 MHz)	–166				
Free path loss	dB	171	–171.1	–172.8	171	
Polarization discrimination	dB	3				
Maximum I per HAPS	dB(W/200 MHz)	–162.6	–160.4	–173	–160.8	
Margin dB	**dB**	**–3.4**	**–5.6**	**7**	**–5.2**	

Analysis of the results in Table 13:

The protection of EESS is given in Recommendation ITU-R RS.2017 which requires in its Table 2 a threshold of –166 dB(W/200 MHz) for 0.1% of the area or the time, within the measurement area of 10 000 000 km^2.

From the data in the above table, the interference level in the EESS receiver is between -160.4 dBW/200 MHz (sensor B2) and –173 dB(W/200 MHz) (EESS sensor B3) which corresponds to a margin between –5.6 dB and 7 dB.

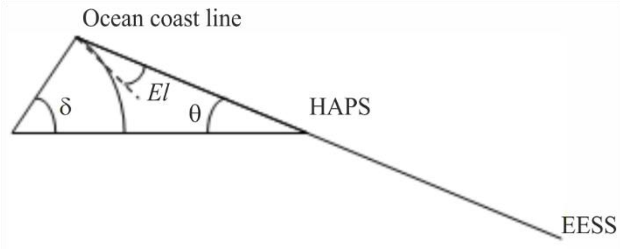
In order to protect the EESS from HAPS emissions, it would be necessary to reduce the interference into the EESS receiver to a level which protects all sensors by an amount equal to 5.6 dB. This can be achieved by reducing the maximum HAPS e.i.r.p. by 5.6 dB for operations over the oceans. For overland operations the margin can be compensated by operating HAPS at a distance from the shore line.

Derivation of the Maximum Sufficient Distance:

EESS sensor measurement are carried out only over oceans therefore, protection e.i.r.p. limitations need only apply to HAPS transmitters emitting only over the oceans or over land at a sufficient distance from an ocean's coast line (measured between the HAPS nadir point and the ocean coast line). Using the following figure and equations the sufficient distance was found to be 29 km.

Using the antenna pattern of Recommendation ITU-R F.1245-1 this distance is 29 km from the coast line.

FIGURE 22



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where:

El : elevation angle in degrees (35° for sensor B2)

θ : is the Nadir angle in degrees.

The distance between the HAPS nadir point and the ocean coast line is determined using the following equation:

$$d = \frac{R_E . sin\left(\frac{\pi}{2} - \theta - El\right) . cos(El)}{sin(\theta)}$$

$$\theta = arcsin\left(\frac{R_E . cos(El)}{(R_E + h)}\right)$$

where:

R_E : Earth radius in m

h : HAPS altitude in m

d : distance in m between the HAPS nadir point and the ocean coast line.

1.2.2.2 Summary and analysis of the results of Study B

The interference level in the EESS receiver is between –163.4 dB(W/200 MHz) (sensor B2) and −176 dB(W/200 MHz) (EESS sensor B3) which corresponds to a margin between –5.6 dB and 7 dB.

The maximum protection deficit of –5.6 dB can be compensated by reducing the maximum HAPS e.i.r.p. This can be achieved by power reduction, by using better performing antennas than the one used in this study or by avoiding operation of HAPS within 29 km from the coast line.

2 Summary and analysis of the results of studies

Both studies provided in this attachment provide consistent results, showing that in order to protect EESS (passive) the e.i.r.p. of HAPS would have to be limited to –34.9 dB(W/200 MHz) (−30.4 dB(W/200 MHz) in band power –4.5 dB exceedance) above 35 degrees elevation.

Such e.i.r.p. limit can be met when considering the actual parabolic antenna pattern as well as the additional attenuation provided by the HAPS structure and should apply to operation of HAPS over the oceans or over the land at a distance lower than 29 km from the ocean coast line (distance between the HAPS nadir point and the ocean coast line).

Annex 5
(Radio astronomy)

Sharing and compatibility of radio astronomy in the band 6 650-6 675.2 MHz and HAPS systems operating in the 6 440-6 520 MHz frequency range

1 Technical analysis

TABLE 14

Scenario considered

HAPS to RAS	X

1.1 Summary

The purpose of the study is to ensure that adequate protection is granted to radio astronomy service operating in the bands 6 650-6 675.2 MHz that may suffer from interference from unwanted emission due to HAPS operating in the band 6 440-6 520 MHz. The analysis is based on the scenario where HAPS communicates to the HAPS ground station in the band 6 440-6 520 MHz. To protect Radio Astronomy service in the band 6 650-6 675.2 MHz from unwanted emission of HAPS in the band 6 440-6 520 MHz the resulting pfd of a HAPS at RAS receivers shall not exceed −210 dB(W/(m^2 · 50 kHz)) for more than 2% of the time. In MHz this corresponds to −197 dB(W/(m^2 · MHz)). This level is based on 30 dBi RAS antenna gain towards HAPS because of the probability of main beam coupling.

1.2 Analysis

1.2.1 HAPS system characteristics

The parameters used in this analysis are given in Table 15:

TABLE 15

HAPS system parameters in the band 6 440-6 520 MHz

HAPS to	HAPS ground station
Number of beams	1
Antenna Pattern	Rec. ITU-R F.1245-2
Antenna gain (dBi)	18.4
Maximum e.i.r.p. spectral density (dBW/Mz) under clear sky conditions	–23
Maximum e.i.r.p. spectral density (dB(W/MHz)) in the band 6 650-6 675.2 MHz	–83
Polarization	RHCP/LHCP

1.2.1.1 Out-of-band HAPS transmitter output filter

It is considered 10 dB attenuation due to the HAPS transmitter filter.

1.2.1.2 HAPS transmitter baseband modulation

The envisaged digital modulation scheme is based on DVB-S waveform that conforms in the baseband with ETSI EN 301 790.

$$H(f) = 1 \qquad for\,|f| < f_N(1-\alpha)$$

$$H(f) = \sqrt{\frac{1}{2}+\frac{1}{2}\sin\frac{\pi\left(f_N-|f|\right)}{2\alpha f_N}} \qquad for\ f_N(1-\alpha)|f| \le |f| \le f_N(1+\alpha)$$

$$H(f) = 0 \qquad for\,|f| > f_N(1+\alpha)$$

where $f_N = \frac{1}{2T_S}$ is the Nyquist frequency and α is the roll-off factor.

The Table below shows applicable roll-of factors for different DVB-S waveforms.

TABLE 16

DVB-S standards and supported roll-off factors

Roll-off factor	DVB-S	DVB-S2	DVB-S2X
0.05			X
0.10			X
0.15			X
0.20		X	
0.25		X	
0.35	X	X	

According to the appropriate roll-off factor, a minimum of 50 dB attenuation for the HAPS to HAPS ground station beam is ensured in the out-of-band domain in order to comply with Recommendation ITU-R SM.1541 applicable to digital fixed service operating above 30 MHz.

1.2.2 Results

The following steps are performed for the sharing study between HAPS emission and radio astronomy receiver:

Step 1: Compute the HAPS antenna gain for all possible elevation angles at the HAPS towards the Earth (–4.5 degrees to –90 degrees). The following figure provides an example for the HAPS to HAPS ground station (HAPS ground station is located at an azimuth of 45 degrees and at an elevation of –70 degrees seen from the HAPS which corresponds to the edge of HAPS coverage).

FIGURE 23

HAPS antenna gain in dBi
(versus elevation angle)

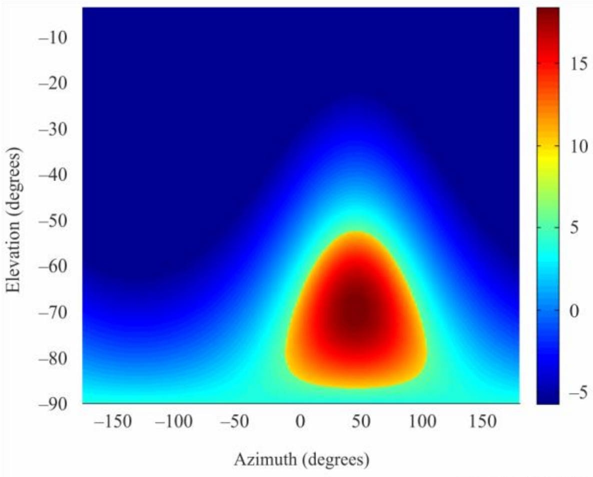

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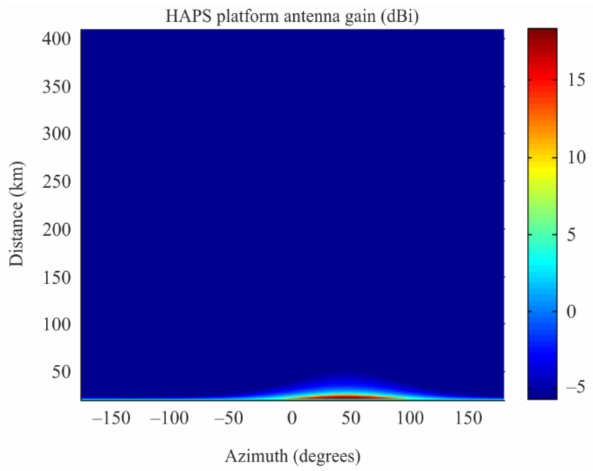
Figure 24 is identical to Fig. 23, but the elevation angles at HAPS has been replaced by the distances from the HAPS nadir point.

FIGURE 24

HAPS antenna gain in dBi
(versus distance from the HAPS nadir point)



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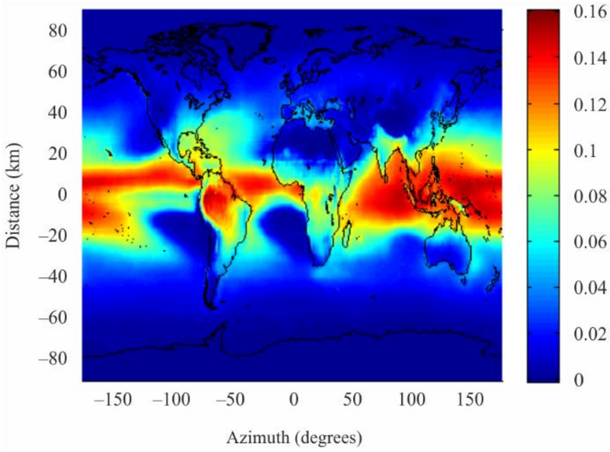
Step 2: Compute the rain attenuation from Recommendation 618 corresponding to P = 2% of the time at the radio astronomy location. Figure 25 below provides the results of rain attenuation in dB for P = 2% and an elevation angle of 45 degrees.

FIGURE 25

Rain attenuation in dB
(*p* = 2% and elevation angle = 45°)



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From the above Figure, it can be concluded that the rain attenuation is negligible in that frequency.

Step 3: The pfd in dB(W/(m^2 · MHz)) level is computed using the following equation:

$$pfd = e.i.r.p.(Az, El) + 10 * log10\left(\frac{1}{4\pi d^2}\right)$$

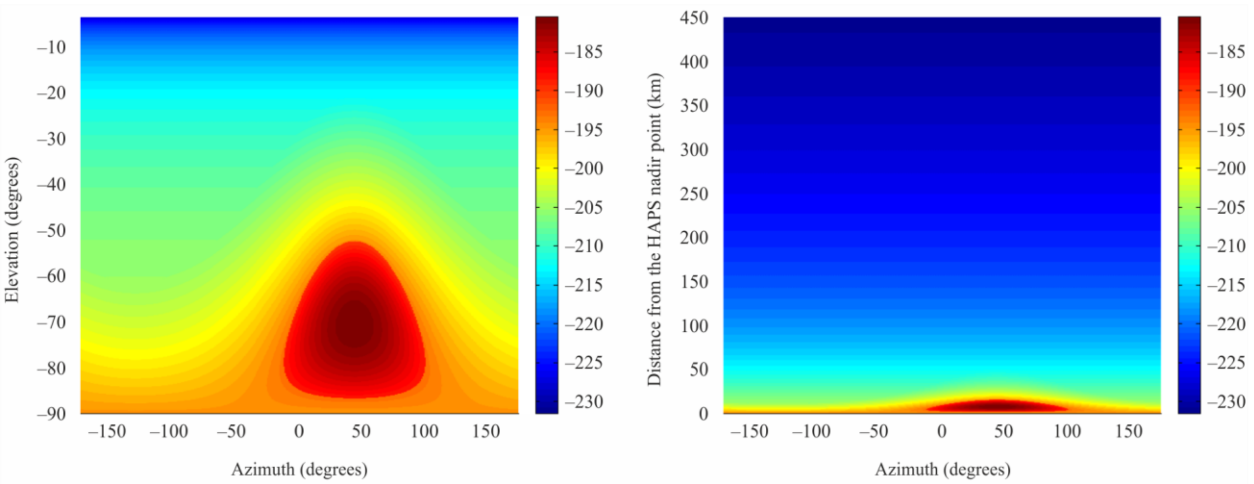
where:

- *e.i.r.p.*: maximum HAPS e.i.r.p. towards the RAS station
- *Az*: azimuth from the HAPS toward the RAS station
- *El*: elevation angle at the HAPS towards the RAS station
- *d*: separation distance in m between the HAPS.

Figure 26 provides an example of the result for the HAPS to HAPS ground station beam.

FIGURE 26

Example of pfd in dB(W/(m^2 · MHz)) from HAPS emission



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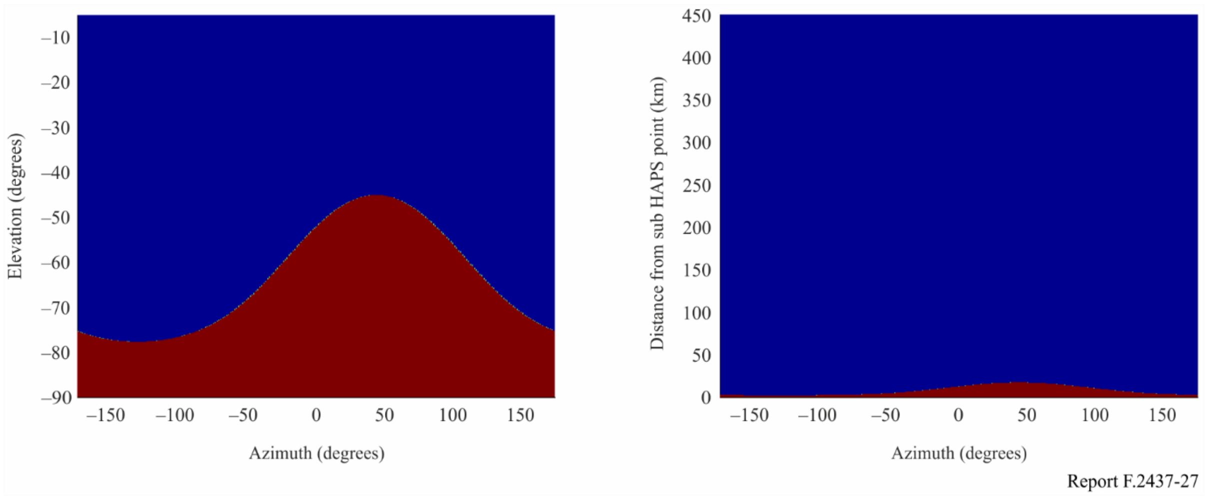
Step 4: Compare the results with the RAS protection criteria: pfd should not exceed −197 dB(W/(m^2 · MHz)) in the radio astronomy band. Figure 27 shows the area where it is exceeded (red area in the Figure) and therefore the area where the RAS station should not be located. In this case, the HAPS location and/or the HAPS beam direction should be modified to comply with the pfd limit to protect the RAS.

FIGURE 27

Example of exclusion zones



2 Summary and analysis of the results of studies

A study has addressed HAPS to HAPS ground station links in the band 6 440-6 520 MHz with regard to RAS in the band 6 650-6 675.2 MHz. The band 6 650-6 675.2 MHz is not allocated to the RAS but is included in RR No. **5.149** which urges administrations to take all practicable steps to protect radio astronomy.

The RAS station performing observations in the band 6 650-6 675.2 GHz can be protected from HAPS downlink transmissions in the band 6 440-6 520 MHz that such HAPS meet unwanted emission pfd values of –210 dB(W/(m² · 50 kHz)) for continuum observations in the 6 650-6 675.2 GHz band at the RAS station location. In order to avoid data loss to RAS systems, when pointing towards HAPS, RAS stations may need to implement angular cones of avoidance around HAPS by up to 1.3 degrees. These pfd values can be met by the HAPS system through a combination of unwanted emission attenuation, separation distance, or limitation of the ground station locations. These pfd values shall be verified considering a percentage of time of 2% in the relevant propagation model.