International Telecommunication Union

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Radiocommunication Sector of ITU

Report ITU-R SM.2450-0
(06/2019)

Sharing and compatibility studies between land-mobile, fixed and passive services in the frequency range 275-450 GHz

SM Series

Spectrum management

International Telecommunication Union

Foreword

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RA	Radio astronomy
RS	Remote sensing systems
S	Fixed-satellite service
SA	Space applications and meteorology
SF	Frequency sharing and coordination between fixed-satellite and fixed service systems
SM	**Spectrum management**

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 SM.2450-0

Sharing and compatibility studies between land-mobile, fixed and passive services in the frequency range 275-450 GHz

(2019)

Overview

This Report contains several studies to assess frequency sharing between passive services (EESS and RAS) and the fixed and land-mobile services in the 275-450 GHz range[1]. The compatibility studies, based on the technical information available on land-mobile service (LMS) and fixed service (FS) characteristics in Reports ITU-R M.2417-0 and ITU-R F.2416-0, seek spectrum that can be used by LMS/FS applications without the need for specific constraints to protect passive service applications (RAS and EESS (passive)). The passive service characteristics are based on Reports ITU-R RA.2189-1 and ITU-R RS.2431-0.

Most of the studies concluded that in the bands 275-296 GHz, 306-313 GHz, 320-330 GHz, and 356-450 GHz only, no specific conditions to protect EESS are necessary, for systems operating within the parameters given in the referenced ITU-R Reports. These studies did not seek to develop conditions (such as power limits, shielding requirements and/or elevation angle restrictions, etc.) that could facilitate sharing with EESS in other frequency bands.

Compatibility studies concluded that atmospheric attenuation independent of free-space losses at 275-450 GHz is not sufficient to provide compatibility between FS and RAS operations in the absence of other considerations. Separation distances and/or avoidance angles between RAS stations and FS stations should be considered depending on the deployment environment of FS stations.

[1] Although RR No. **5.565** also identifies some frequency bands for space research service (passive) applications, no studies have been performed.

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1 Introduction

WRC-19 agenda item 1.15 calls for studies to identify frequency bands for use by administrations for the land mobile and fixed services applications operating in the frequency range 275-450 GHz, in accordance with Resolution **767 (WRC-15)**. Resolution **767 (WRC-15)** invites ITU-R to conduct sharing and compatibility studies between land mobile service (LMS) and fixed service (FS) applications and passive services applications planned to operate in the frequency range 275-450 GHz and to identify candidate frequency bands for use by systems in LMS and FS applications, while maintaining protection of the passive services applications identified in RR No. **5.565**.

This Report provides results of sharing and compatibility studies between LMS and FS applications planning to operate in the frequency range 275-450 GHz and passive services (radio astronomy service and Earth exploration-satellite service (passive)) applications.

1.1 Approach

The approach taken in these studies is to investigate the use of the frequency band 275-450 GHz or portions within the range that could be used for land mobile and fixed service applications without specific conditions, based on the system characteristics identified to-date.

1.2 Organization of the Report

Sections 2 to 4 provide background information in terms of related ITU-R Recommendations and Reports, acronyms and abbreviations used, and relevant information from the Radio Regulations (RR), respectively.

Section 5 summarizes the characteristics of land mobile, fixed, radio astronomy, and Earth exploration-satellite (passive) applications identified to-date.

Section 6 describes specific considerations for sharing and compatibility studies for RAS and EESS (passive).

Section 7 describes the interference scenarios being considered in this Report.

Sections 8 and 9 summarize the results of the sharing and compatibility studies related to EESS (passive) and RAS, respectively.

The detailed analyses are presented in Annexes to this Report, specifically:

Annex 1 summarizes the bands of interest for EESS (passive).

Annex 2 estimates the median building entry loss (BEL) and clutter loss being considered.

Annex 3 provides the antenna radiation pattern used in some studies in Annex 4 and Annex5.

Annex 4 contains the sharing studies between LMS and FS applications and Earth exploration satellite service (EESS passive) applications.

Annex 5 contains the sharing studies between FS applications and radio astronomy service (RAS) applications.

2 Related ITU-R Recommendations and Reports

Recommendation ITU-R F.699	Reference radiation patterns for fixed wireless system antennas for use in coordination studies and interference assessment in the frequency range from 100 MHz to about 70 GHz

Recommendation ITU-R F.1245	Mathematical model of average and related radiation patterns for line-of-sight point-to-point fixed wireless system antennas for use in certain coordination studies and interference assessment in the frequency range from 1 GHz to about 70 GHz
Recommendation ITU-R P.452	Prediction procedure for the evaluation of interference between stations on the surface of the Earth at frequencies above about 0.1 GHz
Recommendation ITU-R P.525	Calculation of free-space attenuation
Recommendation ITU-R P.619	Propagation data required for the evaluation if interference between stations in space and those on the surface of the earth
Recommendation ITU-R P.676	Attenuation by atmospheric gases
Recommendation ITU-R P.840	Attenuation due to clouds and fog
Recommendation ITU-R P.2108	Prediction of Clutter Loss
Recommendation ITU-R P.2109	Prediction of Building Entry Loss
Recommendation ITU-R RA.314	Preferred frequency bands for radio astronomical measurements. This gives frequencies of spectral lines of greatest importance to radio astronomy within the band 275-450 GHz. In this context, the spectral lines of carbon monoxide (CO) at 345.777 GHz and 330.588 GHz are of exceptional importance to radio astronomy
Recommendation ITU-R RA.769	Protection criteria used for radio astronomical measurements
Recommendation ITU-R RA.1031	Protection of the radio astronomy service in frequency bands shared with other services
Recommendation ITU-R RA.1272	Protection of radio astronomy measurements above 60 GHz from ground based interference
Recommendation ITU-R RA.1513	Levels of data loss to radio astronomy observations and percentage-of-time criteria resulting from degradation by interference for frequency bands allocated to the radio astronomy service on a primary basis
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
Recommendation ITU-R RS.2017	Performance and Interference criteria for satellite passive remote sensing
Report ITU-R F.2239	Coexistence between fixed service operating in 71-76 GHz, 81-86 GHz and 92-94 GHz bands and passive services
Report ITU-R F.2416	Technical and operational characteristics and applications of the fixed service operating in the frequency band 275-450 GHz
Report ITU-R M.2417	Technical and operational characteristics and applications of the land mobile service operating in the frequency band 275-450 GHz

Report ITU-R RA.2189	Sharing between the radio astronomy service and active services in the frequency range 275-3 000 GHz
Report ITU-R RS.2194	Passive bands of scientific interest to EESS/SRS from 275 to 3 000 GHz
Report ITU-R RS.2431	Technical and operational characteristics of EESS (passive) systems in the frequency range 275 to 450 GHz
Report ITU-R SM.2352	Technology trends of active services in the frequency range 275-3 000 GHz

3 List of acronyms and abbreviations

BBU	Base band unit
CPMS	Close proximity mobile system
CPMS MT	Close proximity mobile system mobile terminal
CPMS FS	Close proximity mobile system fixed station
EESS	Earth exploration-satellite service
FS IFOV	Fixed service Instantaneous Field of View
LMS	Land mobile service
MIMO	Multiple-input and multiple-output (antenna)
RRH	Remote radio head
RAS	Radio astronomy service

4 Regulatory information above 275 GHz

In the RR there are no frequency allocations above 275 GHz.

The frequency bands for the use for passive service applications are identified in RR No. **5.565**, as shown below:

5.565 The following frequency bands in the range 275-1 000 GHz are identified for use by administrations for passive service applications:

– radio astronomy service: 275-323 GHz, 327-371 GHz, 388-424 GHz, 426-442 GHz, 453-510 GHz, 623-711 GHz, 795-909 GHz and 926-945 GHz;

– Earth exploration-satellite service (passive) and space research service (passive): 275-286 GHz, 296-306 GHz, 313-356 GHz, 361-365 GHz, 369-392 GHz, 397-399 GHz, 409-411 GHz, 416-434 GHz, 439-467 GHz, 477-502 GHz, 523-527 GHz, 538-581 GHz, 611-630 GHz, 634-654 GHz, 657-692 GHz, 713-718 GHz, 729-733 GHz, 750-754 GHz, 771-776 GHz, 823-846 GHz, 850-854 GHz, 857-862 GHz, 866-882 GHz, 905-928 GHz, 951-956 GHz, 968-973 GHz and 985-990 GHz.

The use of the range 275-1 000 GHz by the passive services does not preclude use of this range by active services. Administrations wishing to make frequencies in the 275-1 000 GHz range available for active service applications are urged to take all practicable steps to protect these passive services from harmful interference until the date when the Table of Frequency Allocations is established in the above-mentioned 275-1 000 GHz frequency range.

All frequencies in the range 1 000-3 000 GHz may be used by both active and passive services. (WRC-12)

5 System characteristics

5.1 System characteristics of land mobile service applications operating in the frequency range 275-450 GHz

5.1.1 Close proximity mobile systems

Close proximity mobile systems (CPMS) provide a means for large file sizes to be transferred in a few seconds. Some examples could be systems such as kiosk systems or ticket gate systems, which could be used for the purchase of a movie downloaded to a mobile device. These systems are typically connected to wired networks and provide the wireless data to mobile devices in public areas such as train stations, airports, etc. The distance between the user and the gate or kiosk terminal is typically less than 10 cm.

The expected range of technical and operational characteristics for close proximity mobile systems planned to operate in the band 275-325 GHz and in the band 275-450 GHz are shown in Table 1.

TABLE 1

Expected technical and operational characteristics of a land mobile CPMS applications in the frequency range 275-450 GHz

Parameters	**Values**	
	CPMS application	**Enhanced CPMS application**
Frequency band (GHz)	275-325	275-450
Deployment density (1)	0.6 devices/km^2	0.6 devices/km^2
Tx output power density (dBm/GHz)	−3.8….6.9	−10.1…6.7
Max. e.i.r.p. density(dBm/GHz)	26.2…...36.9	19.9…36.7
Duplex Method	FDD/TDD	FDD/TDD
Modulation	OOK/BPSK/QPSK/16QAM/64QAM BPSK-OFDM/QPSK-OFDM/16QAM-OFDM/32QAM-OFDM/64QAM-OFDM	OOK/BPSK/QPSK/16QAM/64QAM/8PSK/8APSK BPSK-OFDM/QPSK-OFDM/16QAM-OFDM/32QAM-OFDM/64QAM-OFDM
Average distance between CPMS fixed and mobile devices (m)	0.1	0.1

TABLE 1 (*end*)

Parameters	Values	
	CPMS application	**Enhanced CPMS application**
Maximum distance between CPMS fixed and mobile devices (m)	1	1
Antenna height (m)	1…2	–
Antenna beamwidth (degree)	3…10	5…90
Antenna elevation (degree)	±90	±90
Frequency reuse	1	1
Antenna type	Horn	Horn
Antenna pattern	Gaussian	Gaussian
Antenna polarization	Linear	Linear
Indoor CPMS fixed device deployment (%)	100	90
Feeder loss (dB)	2	2
Maximum CPMS fixed/mobile device output power (dBm)	10	10
Channel bandwidth (GHz)	2.16/4.32/8.64/12.96/17.28/25.92/51.8	2.16/4.32/8.64/12.96/17.28/25.92/51.84/69.12/103.68
Transmitter spectrum mask	provided in Fig. 1 and Table 2	provided in Fig. 1 and Table 2
Maximum CPMS fixed device antenna gain (dBi)	30	30
Maximum CPMS mobile device antenna gain (dBi)	15	15
Maximum CPMS fixed device output power (e.i.r.p.) (dBm)	40	40
Maximum CPMS mobile device output power (e.i.r.p.) (dBm)	25	25
Average activity factor (%)	0.76	0.2
Average CPMS fixed device power (dBm (e.i.r.p.))	20	20
Receiver noise figure typical (dB)	15	15

(1) Detailed information of deployment density is provided below.

The following spectrum mask, taken from IEEE Std 802.15.3d-2017, as shown in Fig. 1 and Table 2, is the mask used in CPMS study.

FIGURE 1

Generic transmit spectral mask

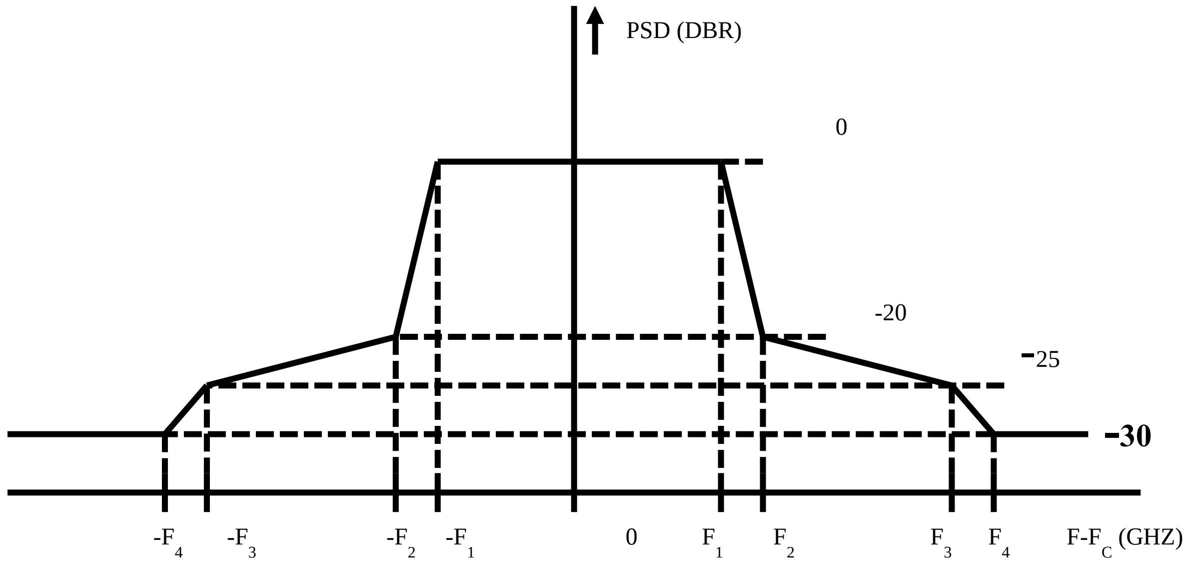


TABLE 2

Transmit spectrum mask parameters

Channel bandwidth (GHz)	f_1 (GHz)	f_2 (GHz)	f_3 (GHz)	f_4 (GHz)
2.160	**0.94**	**1.10**	**1.60**	**2.20**
4.320	**2.02**	**2.18**	**2.68**	**3.28**
8.640	**4.18**	**4.34**	**4.84**	**5.44**
12.960	**6.34**	**6.50**	**7.00**	**7.60**
17.280	**8.50**	**8.66**	**9.16**	**9.76**
25.920	**12.82**	**12.98**	**13.48**	**14.08**
51.840	**25.78**	**25.94**	**26.44**	**27.04**
69.120	**34.42**	**34.58**	**35.08**	**35.68**

Deployment density and activity factor of CPMS stations (Kiosk downloading systems)

Kiosk downloading system, which is mainly deployed indoors, will be used in the stations, airport terminals, convenience stores. Since the number of stations and airports is much smaller than that of convenience stores, the deployment density of kiosk terminals equipped at convenience store should be used for sharing and compatibility studies and station and airport deployments will be ignored. The total number of convenience stores in Japan is 55 129, but 19 571 convenience stores, i.e. 35% of all stores, are distributed in Kanto area whose size is 32 420 km^2, as shown in Table 3. This concludes that deployment density in Kanto is 0.6 stores/km^2 and that in Tokyo 3.28 stores/km^2 which is the maximum density of convenience stores in Japan.

The average number of customers of major convenience stores in Japan is about 1 000/day, but the busiest store which is located nearby stations in Tokyo has the peak number of customers nearly 2 000/day. The following assumption is introduced for estimation of activity factor of CPMS kiosk stations:

1 Average number of customers of convenience store 1 000/day

2	Percentage of customers bringing CPMS devices	20%
3	Downloaded 2-hour movies per CPMS customer	2
4	CPMS device throughput	6.9 Gb/s (see Table 4)
5	Intrinsic time of downloading by one customer	2.2 sec.
6	Total time of downloading	440 sec.
7	Typical opening hour of convenience store	7 am-11 pm (57 600 sec.)
8	Estimated activity factor/store	0.76 %

TABLE 3

Numbers of convenience stores and stations in Kanto area

Metropolitan and Prefecture	Number of convenience store	Size (km^2)
Tokyo	7 183	2 190
Kanagawa	3 765	2 415
Saitama	2 833	3 797
Chiba	2 637	5 157
Ibaraki	1 315	6 096
Gunma	950	6 362
Tochigi	888	6 408
Kanto area (1)	19 571	32 425

(1) Kanto is the regional name including Tokyo metropolitan and the above six prefectures.

TABLE 4

Estimated downloading time of magazine and movie

Content type	File size (MB)	Download time (sec)		
		Throughput 4.6 Gb/s	Throughput 6.9 Gb/s	Throughput 66 Gb/s*
Magazine	300	0.5	0.3	0.03
Movie (2 hour) H.265 (Hi-definition)	900	1.6	1.1	0.11

5.1.2 Intra-device communications

In intra-device communications, high speed terahertz wireless links could connect two or more PCBs or even chips on the same PCB inside a device, simplifying board design, inter module wiring harnesses, etc. Typically, these devices will be shielded, preventing ingress and egress of THz signals. The amount of shielding and the percentage of devices expected to be shielded were not available at the time of this Report. Future studies should consider this information if it is available.

The expected ranges of technical and operational characteristics for wireless THz intra-device links planned to operate in the band 275-450 GHz are shown in Table 5. The transmitter spectrum mask and parameters are the same as those provided for the CPMS application in Fig. 1 and Table 2.

TABLE 5

Expected technical and operational characteristics of wireless THz intra-device links operating in the frequency band 275-450 GHz

Parameter	Value
Frequency band (GHz)	275-450
Deployment density	0.23/km² (1)
Maximum device output power (dBm)	10
Maximum device output power (e.i.r.p.) (dBm)	30
Maximum Tx output power density (dBm/GHz)	−10.1…6.7
Maximum e.i.r.p. density (dBm/GHz)	19.9…36.7
Indoor deployment (%)	50
Duplex method	TDD, FDD, SDD
Modulation	OOK/BPSK/QPSK/16QAM/64QAM 8PSK/8APSK
Maximum distance between devices	<1 m
Antenna height (m)	1…3
Antenna beamwidth (degree)	15…180 (expected)
Frequency reuse	1
Antenna pattern	Gaussian
Antenna polarization	Linear
Channel bandwidth (GHz)	2.16/4.32/8.64/12.96/17.28//25.92/51.84/69.12/103.68
Maximum device antenna gain (dBi)	20
Typical expected device antenna gain (dBi)	6
Maximum device activity (%)	100
Receiver noise figure typical (dB)	10 (2)

(1) The deployment density is estimated as an average based on assuming that every one thousandths citizen in Germany is using such a device. In highly populated cities the density could increase to e.g. 3.95/km² under the same assumptions.

(2) Also systems with a noise figure as low as 8 dB have been reported in publications. This value is a worst case of the published parameters.

5.1.3 Wireless links in data centres

The use of wireless links in data centres aims to provide flexibility by providing reconfigurable routes within a data centre without extensive rewiring. The expected ranges of technical and operational characteristics for wireless links in data centres planned to operate in the band 275-450 GHz are shown in Table 6. This application is intended as a strictly indoor only application. However, the amount of building attenuation loss to be used in the studies is not fully known at this time. See Annex 2 for some discussion for building attenuation loss

A bandwidth of 50 GHz is necessary to achieve a data rate of at least 100 Gbit/s with a simple QPSK modulation and enable compatibility with 100 Gbit/s Ethernet links. The transmitter spectrum mask and parameters are the same as those provided for the CPMS application in Fig. 1 and Table 2.

TABLE 6

Expected technical and operational characteristics of wireless links in data centres operating in the frequency band 275-450 GHz

Parameter	Values
Frequency band (GHz)	275-450
Deployment density	0.07 /km^2
Maximum device output power (dBm)	10
Maximum device output power (e.i.r.p.) (dBm)	40
Tx output power density (dBm/GHz)	−10.1…6.7
e.i.r.p. density (dBm/GHz)	9.9…26.7
Duplex Method	TDD, FDD, SDD
Modulation	OOK/BPSK/QPSK/16QAM/64QAM 8PSK/8APSK
Maximum distance between devices	100 m
Antenna beamwidth (degree)	< 25 (expected)
Frequency reuse	1
Antenna pattern	Gaussian
Antenna polarization	Linear
Indoor deployment (%)	100
Channel bandwidth (GHz)	2.16/4.32/8.64/12.96/17.28/ 25.92/51.84/69.12/103.68
Maximum device antenna gain (dBi)	30
Maximum device activity (%)	100
Receiver noise figure typical (dB)	10

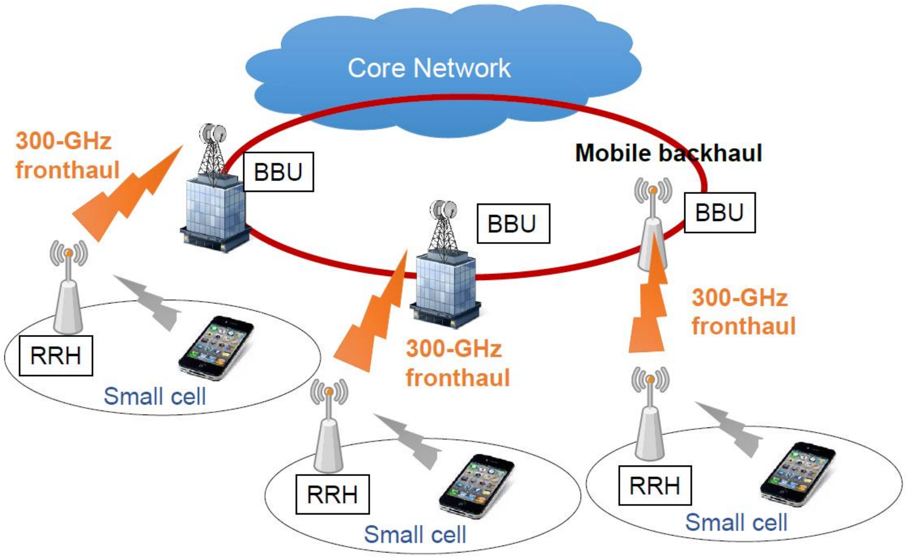
5.2 System characteristics of fixed service applications operating in the frequency range 275-450 GHz

5.2.1 Point-to-point fronthaul and backhaul

Figure 2 shows the network architecture of mobile systems, which support high-capacity transmission between a base station and a mobile terminal. The fronthaul is defined as a link connection between the base station’s baseband unit (BBU) and the remote radio head (RRH), while the backhaul is a link between the base station and the higher level network elements. According to Recommendation ITU-R M.2083 and Report ITU-R M.2376, fronthaul and backhaul are critical challenges to accommodate the increase in data throughput of future mobile traffic. In order to meet the peak data rate 10-20 Gb/s of the mobile terminals in a small cell, the transmission capacity of fronthaul and backhaul may exceed tens of Gb/s substantially.

FIGURE 2

Fronthaul and backhaul operation to be used for mobile system network



The 275-450 GHz range provides the possibility of short range, wide bandwidth, high data rate capability for wireless systems supporting mobile terminals.

The proposed technical and operational characteristics of fixed point-to-point fronthaul and backhaul systems planned to operate in the band 275-325 GHz and 380-450 GHz are shown in Table 7 provided that sharing analysis will show that FS can coexist with the passive services. The transmitter spectrum mask and parameters are the same as those provided for the CPMS application in Fig. 1 and Table 2.

TABLE 7

Technical and operational characteristics of the fixed service applications planned to operate

Frequency band (GHz)	**275-325**	**380-445**
Duplex Method	FDD/TDD	FDD/TDD Note: Other duplex in schemes are possible
Modulation	BPSK/QPSK/8PSK/8APSK/ 16QAM/32QAM/64QAM BPSK-OFDM/QPSK-OFDM/ 16QAM-OFDM/32QAM-OFDM/64QAM-OFDM	BPSK/QPSK/8PSK/8APSK/ 16QAM/32QAM, 8PSK, 8APSK BPSK-OFDM/QPSK-OFDM/ 16QAM-OFDM/ 32QAM-OFDM
Channel bandwidth (GHz)	2…..25 (FDD) 2…..50 (TDD)	2…..32.5 (FDD) 2…..65 (TDD)

TABLE 7 (*end*)

Frequency band (GHz)	275-325	380-445
Spectrum mask	See § 5.1.1	See § 5.1.1
Tx output power range (dBm)	0….20	−10….10
Tx output power density range (dBm/GHz)	−17……17	−28….7
Feeder/multiplexer loss range (dB)	0 … 3	0 … 3
Antenna gain range (dBi)	24 … 50	24 … 50
e.i.r.p. range (dBm)	44…..70	37……60
e.i.r.p. density range (dBm/GHz)	30……67	19…..57
Antenna pattern	Rec. ITU-R F.699 (Single entry) Rec. ITU-R F.1245 (Aggregate)	Rec. ITU-R F.699 (Single entry) Rec. ITU-R F.1245 (Aggregate)
Antenna type	Parabolic Reflector	Parabolic Reflector
Antenna height (m)	6-25	10-25
Antenna elevation (degree)	±20 (typical)	±20 (typical)
Receiver noise figure typical (dB)	15	15
Receiver noise power density typical (dBm/GHz)	−69	−69
Normalized Rx input level for 1 × 10-6 BER (dBm/GHz)	−61 … −54	−61 … −54
Link length (m)	100 … 300	100 … 300
Deployment Density	See below	See below
I/*N* protection criteria	Rec. ITU-R F.758	Rec. ITU-R F.758

Estimation of maximum density of FS links

According to Recommendation ITU-R M.2101, the deployment scenarios of radio access networks for IMT are categorized into four base station locations, i.e. rural, suburban, urban and indoor. Suburban and urban scenarios are further divided into macro and micro locations whose coverage areas are distinguished. The coverage areas of the micro scenario are included in the macro area.

The fixed service applications such as fronthaul and backhaul links are expected to provide a high capacity link between BBU and RRH. The location of BBU may correspond to the macro-cellular base station and that of RRH to the micro-cellular base station, in both urban and suburban areas. However, due to the distance between the BS in suburban areas, the FS links operating in the range 275-450 GHz are assumed to be used only in urban environment whereas other links will be connected through other RF bands which are already allocated to the fixed service.

The density of BS in urban areas is estimated to 30 BS/km^2 in each of the frequency ranges expected for IMT-2020 (i.e. 24.25-33.4 GHz, 37-43.5 GHz, 45.5-52.6 GHz and 66-86 GHz)[2]. The FS link in the 275-450 GHz range will be used for ultra-high-capacity link for dense urban area only. Although

[2] Document 5-1/36, "Characteristics of terrestrial IMT systems for frequency sharing/interference analyses in the frequency range between 24.25 GHz and 86 GHz".

the percentage of dense urban area per 1 km^2 is not specifically indicated in any ITU-R publications, a ratio of 7% of BS is assumed in dense urban areas.

According to this assumption, the total number of BS in Tokyo metropolitan district is calculated by 7% of 120 BS multiplied by 619 km^2, i.e. 5,200, as shown in Table 8, for the whole 275-450 GHz band. The other major city in Japan is also included in Table 8. This calculation shows that a density of 8.4 FS links/km^2 can be expected in the whole range 275-450 GHz, hence considering a density of 4.2 FS link/km^2 in each of the 275-325 GHz and 380-445 GHz bands for the evaluation of aggregate effect of emission from FS links.

Although only based on some highly populated cities in Japan, this 4.2 FS link/km^2 figure is assumed to be globally representative. Alternatively, another way of addressing the FS links distribution could be to use population densities together with the above ratio of 0.0007 links /inhabitant (for the whole 275-450 GHz range), i.e. a density of 0.00035 FS links/inhabitant in each of the 275-325 GHz and 380-445 GHz bands.

TABLE 8

Calculation of FS links in the 275-450 GHz range for some highly populated cities in Japan

Name of city	Size (km^2)	Population (M)	No. of FS links	FS links / $km^{2(1)}$	FS links / inhabitant
Tokyo district	619	9.37	5200	8.4	0.0006
Yokohama	437.4	3.73	3674	8.4	0.0010
Osaka	223	2.70	1873	8.4	0.0007
Nagoya	326.4	2.30	2742	8.4	0.0012
Total	1605.8	18.1	13489	8.4	0.0007

(1) The FS link density is estimated on the condition that all four proposed millimetric waves will be regulated to use for IMT-2020 services.

Elevation angles of antenna

The antenna heights of the base stations in the urban area are estimated in the range 6-25 m. The elevation angles of the antenna are calculated from the antenna height of FS stations and the distance between FS links. Although the distance between the base stations in the dense urban area is also indicated to be 200 m, the distance range of 100-300 m is assumed to be used for calculation of elevation angle of antenna.

In the metropolitan area of Tokyo, the elevation angle is estimated to be less than ±12 degree taking into account the above parameters as well as the surface deviation of Tokyo area.

In order to taking in account the different urban are around the world, it is assumed that a typical elevation would be ±20.

Channel arrangement and spectrum need

According to spectrum need of IMT system in the frequency range between 24.5 GHz and 86 GHz, one study result shows the estimated spectrum need of 18.7 GHz, and another study result was that of 27.4 GHz which includes indoor hotspot system[3].

[3] Document 5-1/36 "Liaison statement to Task Group 5/1 – Spectrum needs for the terrestrial component of IMT in the frequency range between 24.5 GHz and 86 GHz".

Taking into account these study results, the channel bandwidth of 24.5 GHz is sufficient to provide high-capacity link for fronthaul/backhaul for IMT system. If the requirements are similar, the same bandwidth of around 25 GHz may satisfy the initial typical deployment scenarios.

According to the previous discussion a total long term spectrum bandwidth of about 50 GHz will sufficiently support the evolution of IMT traffic between BBU and RRH. The possible candidate frequency bands for fronthaul and backhaul applications are 275-325 GHz and 380-445 GHz. The frequency band 330-370 GHz may also be considered in the future, if and when parameters are available for that range.

5.3 System characteristics of the radio astronomy service operating in the frequency range 275-450 GHz

Table 9 and Table 10 provide threshold levels of interference to radio astronomy analogous to those found in Recommendation ITU-R RA.769, but for frequency bands of present interest. Entries just below and above the range 275-450 GHz are provided for purposes of interpolation. Table 11 lists the locations of eleven radio astronomy stations currently conducting operations in the band 275-450 GHz, and one site proposed to conduct such operations. The mean altitude of these sites is 3 500 m: most are above 4 000 m. Their local geography and more detail may be found using the IUCAF world map of radio telescopes and radio quiet zones at http://tinyurl.com/yrvszk.

TABLE 9

Threshold levels of harmful interference to radio astronomy continuum observations

Centre frequency (1) f_c (MHz)	Assumed bandwidth Δf (MHz)	Minimum antenna noise temperature T_A (K)	Receiver noise temperature T_R (K)	System sensitivity (noise fluctuations)		Threshold interference levels		
				Temperature ΔT (mK)	Power spectral density, ΔP (dB(W/Hz))	Input power ΔP_H (dBW)	pfd $S_H \Delta f$ (dB(W/m^2))	Spectral pfd S_H (dB(W/(m^2 · Hz)))
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
265 000	8 000	20	75	0.024	−274.8	−185.8	−115.9	−214.9
345 000	8 000	30	100	0.032	−273.5	−184.5	−112.2	−211.3
405 000	8 000	60	215	0.069	−270.2	−181.2	−107.6	−206.6
432 000	8 000	73	275	0.087	−269.2	−180.2	−106.0	−205.0
500 000	8 000	110	385	0.124	−267.7	−178.6	−103.2	−202.2

TABLE 10

Threshold levels of harmful interference to radio astronomy spectral-line observations

Frequency f (MHz)	Assumed spectral line channel bandwidth Δf (kHz)	Minimum antenna noise temperature T_A (K)	Receiver noise temperature T_R (K)	System sensitivity (noise fluctuations)		Threshold interference levels		
				Temperature ΔT (mK)	Power spectral density ΔP_S (dB(W/Hz))	Input power ΔP_H (dBW)	pfd $S_H \Delta f$ (dB(W/m^2))	Spectral pfd S_H (dB(W/(m^2 Hz)))
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
265 000	1 000	20	75	2.12	−255.3	−205.3	−135.4	−195.4
345 000	1 000	30	100	2.91	−254.0	−204.0	−131.8	−191.8
405 000	1 000	60	215	6.15	−250.7	−200.7	−127.1	−187.1
432 000	1 000	73	275	7.78	−249.7	−199.7	−125.5	−185.5
500 000	1 000	110	385	11.07	−248.2	−198.2	−122.7	−182.7

TABLE 11

Radio Astronomy sites operating at 275-450 GHz

ITU-R Region 1

Observatory name, place, administration	Longitude (E), Latitude (N), Elevation (m AMSL)	Minimum elevation (degrees)	Rx height above terrain (m)	Geographical characteristics
IRAM-NOEMA 12×15 m Array, Plateau de Bure, France	5.9079173°, 44.633889° (2553)	0	15	Isolated mountaintop plateau in partial view of public facilities
IRAM-30 m, Pico de Veleta, Spain	–3.392778°, 37.06611° (2850)	0	31	Mountainside overlooking nearby ski resort and the city of Granada

ITU-R Region 2

Observatory name, place, administration	Longitude (E), Latitude (N), Elevation (m AMSL)	Minimum elevation (degrees)	Rx height above terrain (m)	Geographical characteristics
LMT 50 m Sierra Negra, Puebla, Mexico	–97.313333°, 18.985000° (4660)	7	51	Mountain top in line of sight to numerous towns and 15 km from Mexico City-Puebla-Veracruz highway
APEX 12 m – Atacama Pathfinder Experiment, Chajnantor, Chile	−67.75888°, −23.00583° (4850)	0	13	Broad flat high plain ringed by mountains, accessible by road
ASTE 12 m – Atacama Submillimeter Telescope Experiment, Chajnantor, Chile	−67.7033°, −22.97158° (4775)	0	13	Broad flat high plain ringed by mountains, accessible by road
ALMA, 54×12 m+12×7 m Chajnantor, Chile	–67.754928° –23.022911° (4800)	0	13	Broad flat high plain ringed by mountains, accessible by road, 35 km diameter circle centred on the given coordinates
NANTEN2 4 m, Pampa La Bola, Chile	–67.702222° –22.296306° (4750)	0	7	Broad flat high plain accessible by public road
ARO SMT 10 m, Mt. Graham, AZ, USA	–109.89201° 32.701303° (3200)	7	11	Remote forested mountaintop
JCMT 15 m, SMA 6×6 m & CSO 12 m; Mauna Kea, HI, USA	–155.47500° 19.821667° (4300)	6	17	Isolated very high mountaintop
South Pole 10m Telescope, NSF South Pole Research Station	…… −90° (2820)	0	8	At the very South Pole

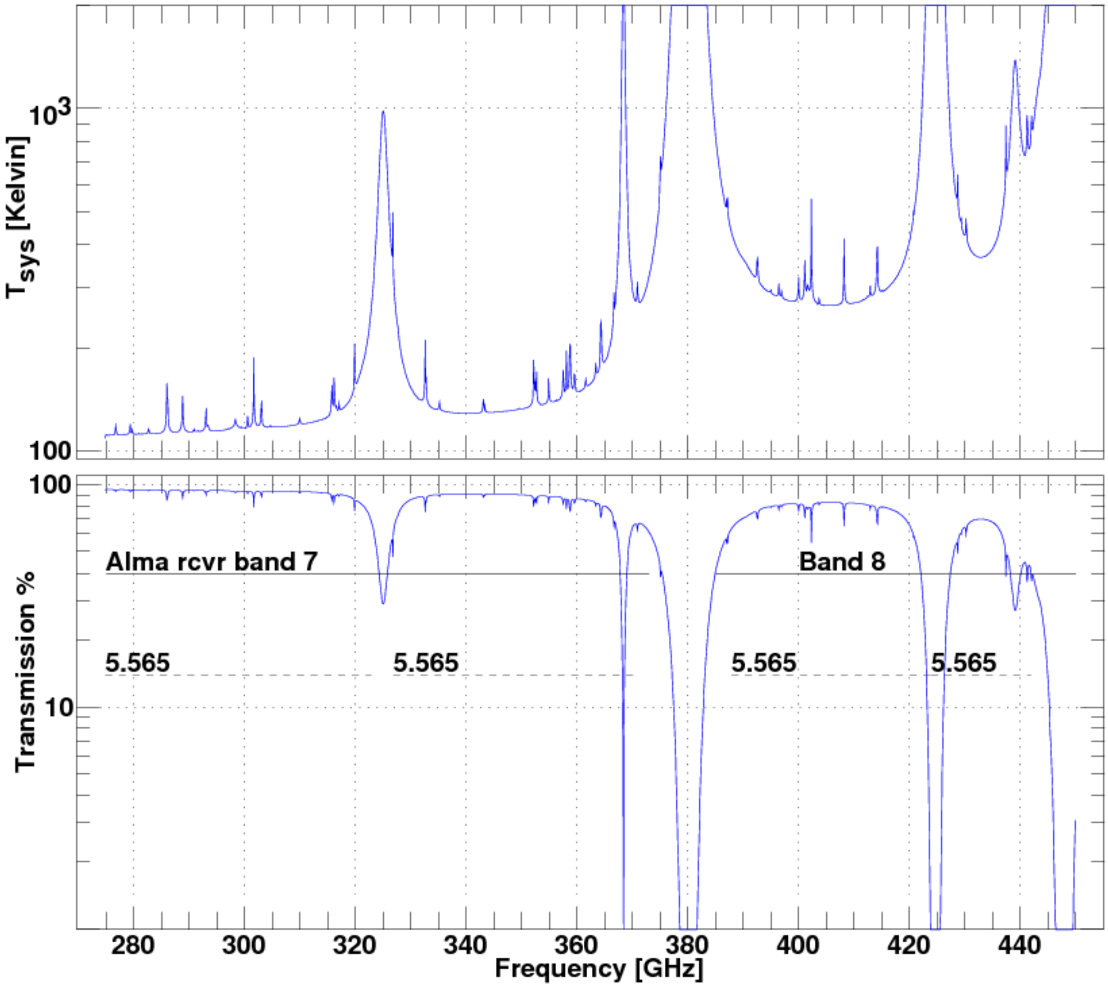
Observatory name, place, administration	Longitude (E), Latitude (N), Elevation (m AMSL)	Minimum elevation (degrees)	Rx height above terrain (m)	Geographical characteristics
Simons Array and Simons Observatory, Chile	−67.7875°, −22.95861° (5200)	0	6	Broad flat high plain ringed by mountains, accessible by road

ITU-R Region 3

Observatory name, place, administration	Longitude (E), Latitude (N), Elevation (m AMSL)	Minimum elevation (degrees)	Rx height above terrain (m)	Geographical characteristics
CCOSMA, 3m, Yangbajing, Tibet China	90.5258°, 30.1033° (4319)	0	4	Broad flat high plain ringed by mountains, accessible by road
HEAT, 5m, Dome A, South Pole, China (proposed)	70.116111°, −80.416944° (4087)	0	6	Top of the mountain at the broad flat high plain, remote place

FIGURE 3

Zenith system temperature and atmospheric transmission at ALMA



Upper plot: Variation of system temperature at ALMA with frequency, including sky, atmospheric and receiver contributions. The system temperature shown here is the sum of T_A and T_R in Tables 1 and 2 of Annex 1 to Recommendation ITU-R RA.769, and it is equal to the quantity T in equation (3) of Recommendation ITU-R RA.769 (i.e. $T = T_A + T_R = T_{sys}$).

Lower plot: Atmospheric transmission as a function of frequency. The tuning ranges of Alma receiver bands 7 and 8 are shown, as well as the frequency ranges mentioned in RR No. **5.565**.

5.4 System characteristics of Earth exploration-satellite service (passive) operating in the frequency range 275-450 GHz

Between 275 and 450 GHz, a number of bands of scientific interest for studies of meteorology/climatology and atmospheric chemistry have been identified and are listed in Annex 1 of this Report. Meteorology/climatology sensing is focused mainly on the water vapour and oxygen resonance lines and the associated frequency windows to retrieve these necessary physical parameters, while atmospheric chemistry sensing measures the many smaller spectral lines of the various atmospheric chemical species. In some cases, a single molecule is observed in several different frequency bands due to, as an example, different frequency bands being sensitive to the particular molecule at different altitudes.

Recommendation ITU-R RS.2017 provides the permissible interference levels for EESS passive remote sensing systems. Table 12 provides an extract from that recommendation that covers the frequency range 275-450 GHz. It should be noted that these protection criteria are aggregate levels of maximum interference and have to be apportioned among all various sources, in-band and adjacent band. Under WRC-19 agenda item 1.15 these criteria, where appropriate, will have to be apportioned between the FS, the MS and potentially the unwanted emissions from FS and MS.

TABLE 12

Extract of Recommendation ITU-R RS.2017 showing the interference criteria for satellite passive remote sensing in the frequency range 275-450 GHz

Frequency band(s) (GHz)	Reference bandwidth (MHz)	Maximum interference level (dBW)	Percentage of area or time permissible interference level may be exceeded(1) (%)	Scan mode (*N*, *C*, *L*)(2)
275-285.4	3	−194	1	*L*
296-306	200/3(3)	−160/−194(3)	0.01/1(3)	*N*, *L*
313.5-355.6	200/3(3)	−158/−194(3)	0.01/1(3)	*N*, *C*, *L*
361.2-365	200/3(3)	−158/−194(3)	0.01/1(3)	*N*, *L*
369.2-391.2	200/3(3)	−158/−194(3)	0.01/1(3)	*N*, *L*
397.2-399.2	200/3(3)	−158/−194(3)	0.01/1(3)	*N*, *L*
409-411	3	−194	1	*L*
416-433.46	200/3 (3)	−157/−194(3)	0.01/1(3)	*N*, *L*
439.1-466.3	200/3 (3)	−157/−194(3)	0.01/1 (3)	*N*, *C*, *L*

(1) For a 0.01% level, the measurement area is a square on the Earth of 2 000 000 km^2, unless otherwise justified; for a 0.1% level, the measurement area is a square on the Earth of 10 000 000 km^2 unless otherwise justified; for a 1% level, the measurement time is 24 h, unless otherwise justified.

(2) *N*: Nadir. *L*: Limb, *C*: Conical.

(3) First number for nadir or conical scanning modes and second number for microwave limb sounding applications.

Concerning the different types of EESS (passive) sensors to be considered in these studies, they are defined as follows:

– *N*: Nadir scan modes concentrate on sounding or viewing the Earth's surface at angles of nearly perpendicular incidence. The scan terminates at the surface or at various levels in the atmosphere according to the weighting functions used to assess particular atmospheric parameter.

– *L*: Limb scan modes view the atmosphere "on edge" and its view terminates in space rather than at the surface of the Earth, and accordingly have a weighting function value of zero at the surface and has a maximum value at the tangent point height.

– *C*: Conical scan modes view the Earth's surface by rotating the antenna at an offset angle from the nadir direction.

Figure 4 depicts these three types of sensors. It is further noted that the nadir type of sensors include all different sensors implementations that have at least one nadir viewing component, such as cross-track and push-broom.

FIGURE 4

Nadir, Limb, and Conical scanning modes of the EESS (passive) sensor

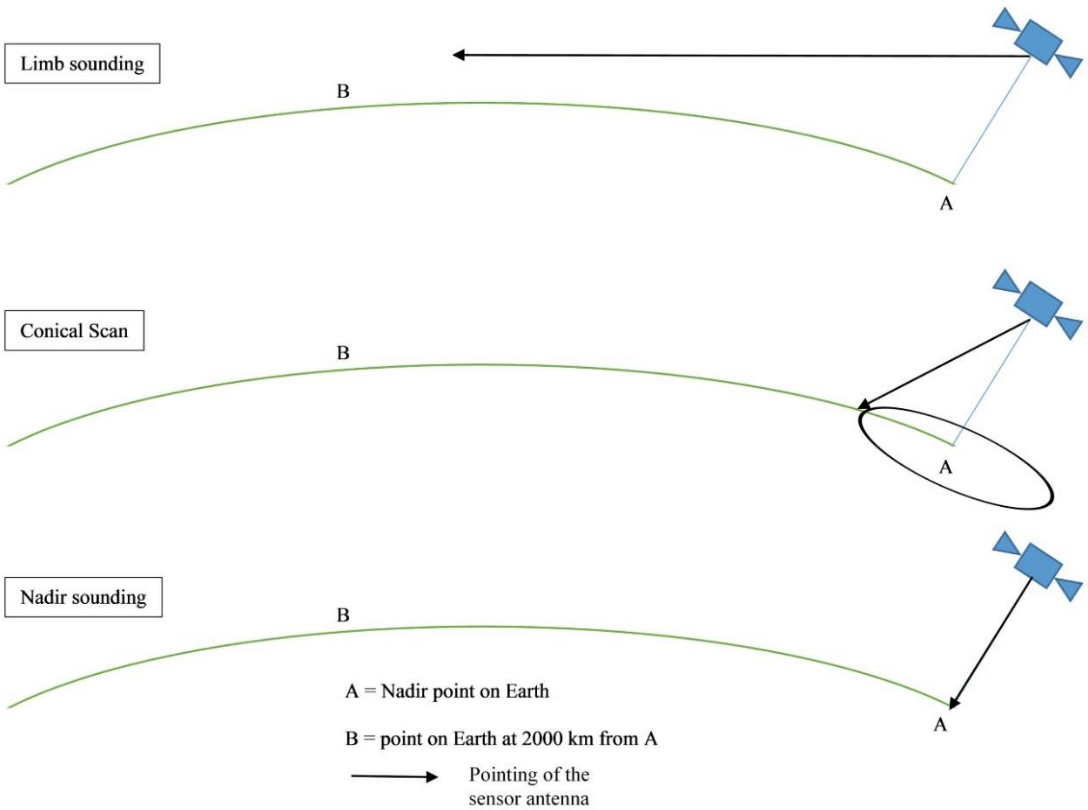


Table 13 provides a band-by-band summary of EESS (passive) systems to be considered in sharing studies in the frequency range 275-450 GHz. The parameters necessary for conducting studies are summarized in Table 14. The detailed characteristics of these EESS (passive) systems are provided in Report ITU-R RS.2431.

TABLE 13

Satellite passive remote sensing systems for the bands in the frequency range 275-450 GHz[4]

<table>
<tr><th rowspan="2">Frequency band(s) (GHz)</th><th rowspan="2"></th><th colspan="2">Scan mode</th></tr>
<tr><th>Nadir, Conical</th><th>Limb</th></tr>
<tr><td>275-285.4</td><td>L</td><td>---------</td><td>Consider characteristics similar to STEAMR (Note 1)</td></tr>
<tr><td>296-306</td><td>N, L</td><td>Consider characteristics similar to STEAMR (Note 1)</td><td>MASTER (LEO orbit, Section 6.9)</td></tr>
<tr><td>313.5-355.6</td><td>N, C, L</td><td>ICI (LEO orbit, Section 6.1)
SSM (LEO orbit, Section 6.3)
GEM (GEO orbit, Section 6.5)</td><td>STEAMR (LEO orbit, Section 6.4)
CAMLS (LEO orbit, Section 6.7)
MASTER (LEO orbit, Section 6.9)</td></tr>
<tr><td>361.2-365</td><td>N, L</td><td>Consider characteristics similar to ICI (Note 1)</td><td rowspan="6">Consider characteristics similar to STEAMR (Note 1)</td></tr>
<tr><td>369.2-391.2</td><td>N, L</td><td>TWICE (LEO orbit, Section 6.2)
GEM (GEO orbit, Section 6.5)
GOMAS (GEO orbit, Section 6.6)</td></tr>
<tr><td>397.2-399.2</td><td>N, L</td><td>Consider characteristics similar to ICI (Note 1)</td></tr>
<tr><td>409-411</td><td>L</td><td>---------</td></tr>
<tr><td>416-433.46</td><td>N, L</td><td>GOMAS (GEO orbit, Section 6.6)</td></tr>
<tr><td>439.1-466.3</td><td>N, C, L</td><td>ICI (LEO orbit, Section 6.1)</td></tr>
</table>

NOTE 1 – For some of the bands for which parameters of current operating or planned systems are not available characteristics based on systems with the same scan mode in other bands are to be used.

4 References to sections within this Table are in regards to sections in Report ITU-R RS.2431.

TABLE 14

Summary of technical characteristics of EESS (passive) systems in 275-450 GHz frequency range (see Report ITU-R RS.2431)

Instrument	ICI	TWICE	SMM	STEAMR	GOMAS	GEM	CAMLS	MASTER	GMS
Type of Orbit	SSO LEO	SSO LEO	SSO LEO	SSO LEO	GSO	GSO	LEO	SSO LEO	GSO
Altitude (km)	817	400	not available	817	35 684	35 684	not available	817	35 684
Inclination (degrees)	98.7	High inclination	High inclination	98.7	0	0	not available	98.7	0
Scanning mode	Conical (Fig. 10)	Conical (Fig. 11)	Conical or cross track (Fig. 13)	Limb (Fig. 15)	Conical (Fig. 17)	Conical	Limb	Limb	wide strip and thin circle combined scan (Fig. 9)
Observation Zenith Angle (OZA) (degrees) for conical scan, or Min. pointing altitude (km), for limb scan	Conical: 53 ± 2	Conical: 53	not available	Limb: 6	not available	not available	Limb: 10	Limb: 3	**N/A**
RF Centre Frequency (GHz)	325.15 448	310 380.2	325	319.5 349.6	380.197 424.763	380.197 425.763	340	299.75 320.0 345.6	338 380.197 424.763
RF Bandwidth (GHz)	3.2-6 2.4-6 (Table 4)	10 7.2	not available	12 12	0.3-4 0.06-1 (Table 12)	0.05-18 (LSB)	16	11.5 9.0 6.5	0.03-8 0.01-1
Antenna type	Offset reflector, multiple feeds	Broadband multi-flare horns	not available	Reflector antenna	Filled aperture scanning	Filled aperture scanning	not available	Elliptical Offset reflector	Reflector Antenna
Antenna Peak Gain (dBi)	55	46-48 (TBC)	not available	70	not available	not available	not available	not available	**76**
Antenna Diameter (m)	~ 0.5	not available	not available	not available	3	2	not available	1 × 2	3
Antenna Beamwidth (degrees)	not available	0.64º 0.56º	not available	See Fig. 15	0.019º 0.017º	0.029º 0.026º	not available	not available	0.027°
FOV (km) Footprint area (km²)	16 Area ≈ 200 km² (Table 3)	FOV: 6.5 × 9.9 Area ≈ 50 km² FOV: 5.8 × 8.7 Area ≈ 40 km² (Fig. 6.2-2)	not available	N/A (See Fig. 15)	IFOV: 12 Area ≈ 110 km² IFOV: 10 Area ≈ 75 km²	FOV: 20.5 Area ≈ 330 km² FOV: 16.4 Area ≈ 210 km²	N/A (See Table 13)	N/A (See Table 17)	IFOV: 16

It should be noted that Recommendation ITU-R RS.1813 is currently limited to the 1.4 to 100 GHz range for its reference EESS (passive) antenna pattern equations. However, it is recommended by the responsible ITU-R expert working group that the antenna pattern equations in Recommendation ITU-R RS.1813 should also be used in the 275-450 GHz range for these studies.

6 Considerations for sharing and compatibility studies

6.1 RAS

The potential for interference to radio astronomy by proposed active service use of the frequency band 275-450 GHz differs from other inter-service interference cases because of the particular properties of the atmospheric absorption (see Figs 3, 4 and A5-1) and because of the geographic location of radio astronomy stations using the band (Table 11). These stations are generally located at elevations of 3 to 5 km in arid areas so as to minimize precipitation and atmospheric absorption around and above the radio astronomy antenna.

In the frequency band 275-450 GHz modest-size active service antennas have narrow beamwidths that are not feasible in lower frequency bands. Although narrow beamwidths and a predominance of low elevation angles are expected for FS applications, selection of appropriate antennas and careful planning of link directions may be necessary to avoid harmful interference to radio astronomy.

Above 275 GHz, propagation through the Earth's atmosphere is strongly affected by the absorption characteristics of atmospheric molecules, most notably oxygen and water vapour. While atmospheric attenuation may offer additional protection to RAS operations at certain frequencies, due to the large variation of atmospheric molecules as a function of height, there are transmission "windows" approaching free space loss at higher altitudes.

Report ITU-R RA.2189-1 concluded that at the emission powers considered there, sharing between radio astronomy and active services in the band 275-3 000 GHz is possible if atmospheric characteristics as a function of height above sea level, as well as transmitter antenna directivity, are taken into account. Harmful interference to radio astronomy facilities can be avoided through the use of geographic exclusion zones surrounding RAS facilities. Direct illumination of RAS observatories, primarily at altitudes comparable to or above those of the observatories, could cause interference to RAS systems.

Apart from exclusion zones, two basic strategies are possible for protecting the RAS in these bands from fixed service emissions. The first involves lower powers and narrow beam antennas, and the second involves avoiding pointing toward RAS facilities. While this should be straightforward for most fixed service point-to-point uses, it is not applicable to some other terrestrial applications such as mobile use.

FIGURE 5

Atmospheric attenuation computed over horizontal paths of 1 km at five different heights above sea level, as well as annually-averaged and 10th percentile observing conditions at the ALMA and LMT/GTM radio astronomy observatory sites, assuming the atmospheric properties of Table 1 from RA.2189-1

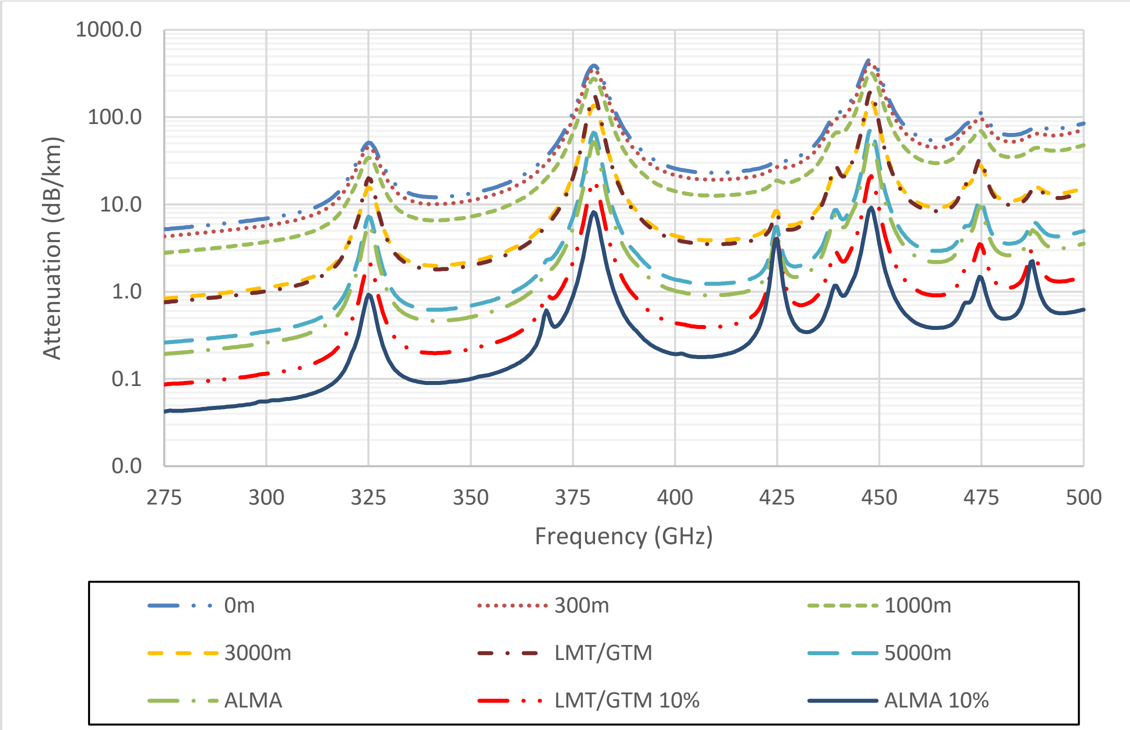
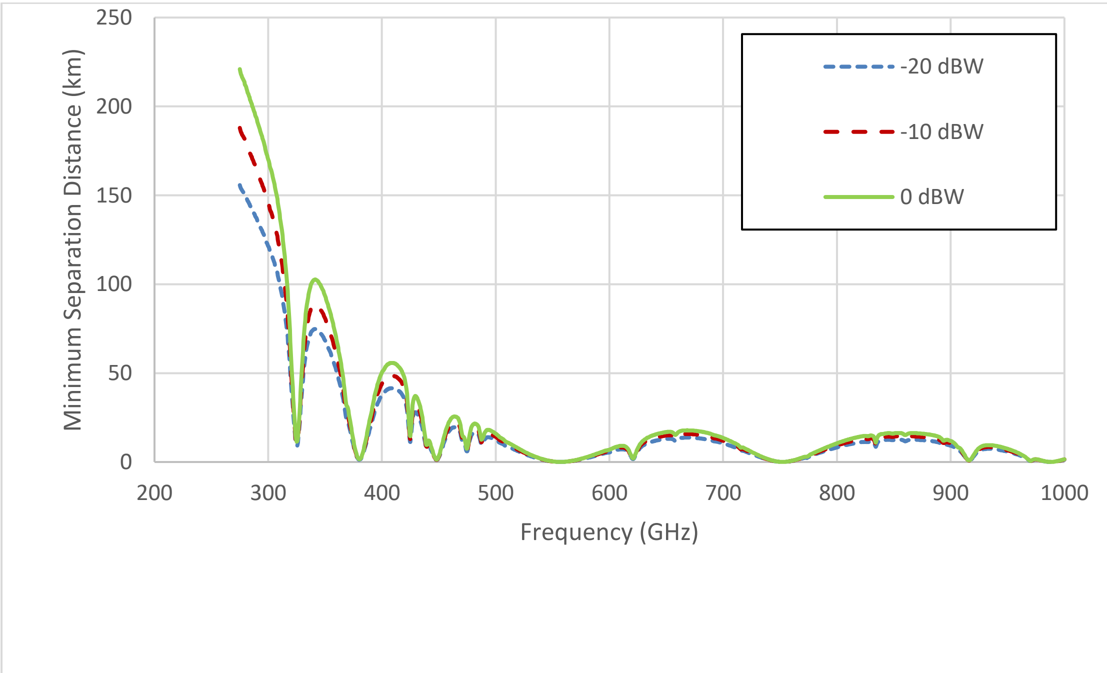


FIGURE 6

Horizontal distance at 5 000 m above sea level beyond which a transmitted signal at frequencies between 275 and 1 000 GHz would not exceed radio astronomy interference thresholds from Rep. ITU-R RA.2189-1, highlighting need for a combination of geographic exclusion zones and avoidance of direct illumination to protect RAS operations



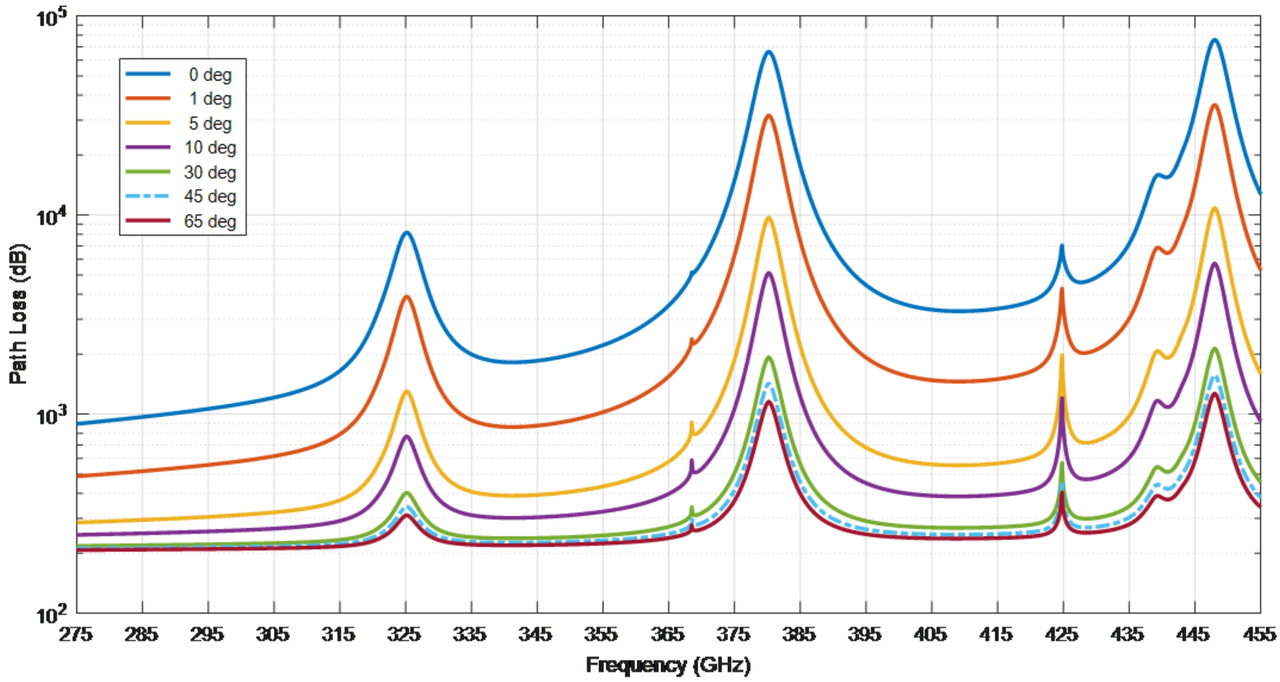
6.2 EESS (passive)

The total path loss from a low elevation angle Fixed Service link to a NGSO EESS satellite rising over the horizon at the azimuth of the FS link is a complex calculation due to both the refraction of the signal path as its height above the earth changes and the change of attenuation with atmospheric pressure, temperature, and water vapour. Section 2.2 of Annex 1 to Recommendation P.676-11 gives an appropriate algorithm for such calculations. However, the calculation does not take into account blocking by natural or building obstructions, which would reduce or eliminate interference to EESS (passive) sensors in some cases. Therefore, dynamic simulations of FS and land-mobile interference into EESS (passive) sensors need to take into account the probability of natural and building obstructions, which would reduce interference in those cases where obstructions would exist. Similarly, any estimate of aggregate interference from FS systems will have to consider blockage of some fraction of sources.

Figures 7 and 8 show average path loss from terrestrial FS transmitter at different elevation angles to a satellite in orbit at a height of 817 km[5].

FIGURE 7

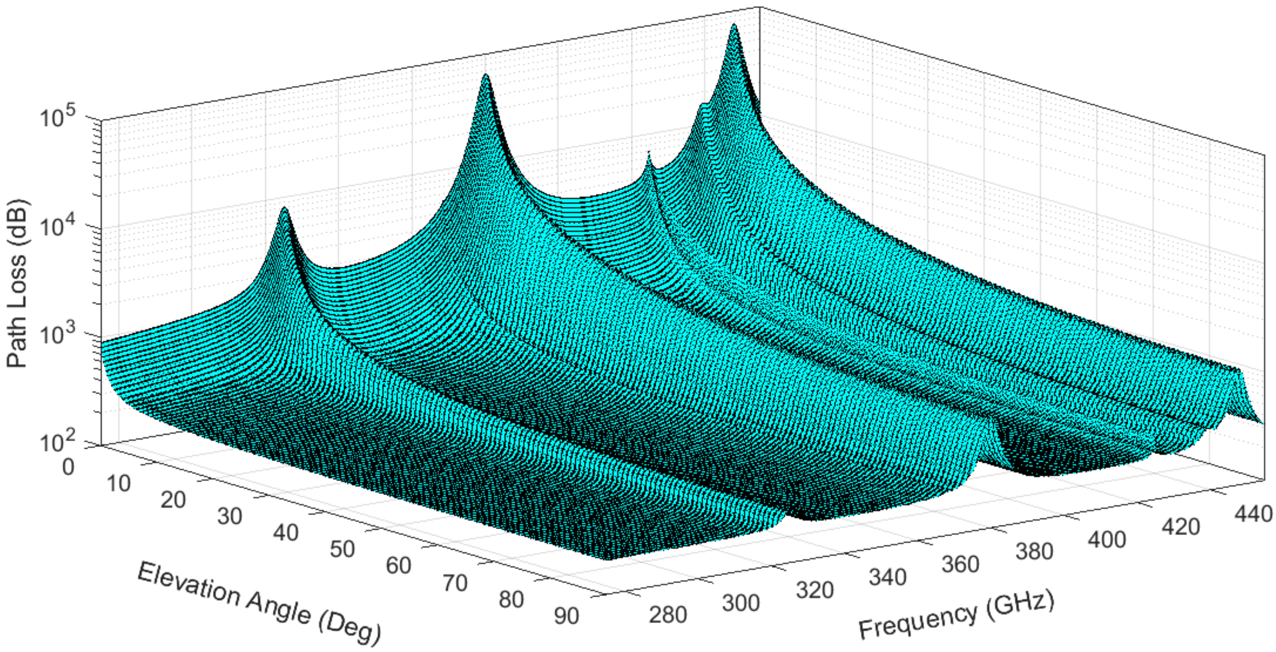
Average path loss from a terrestrial point to a Satellite (H= 817 km) as a function of elevation angle



5 The altitude 817 km is a typical EESS NGSO orbit height. Results will vary a small amount for other heights.

FIGURE 8

3D representation of Fig. 7



Figures 7 and 8 are based on the sum of two types of 'permanent' (i.e. always present) losses:

– average losses due to atmospheric gases, and

– losses due to geometrical spreading of energy (free space path loss).

Losses due to atmospheric gases were computed using both the line-by-line method of Annex 1 and § 2.2 of Recommendation ITU-R P.676-11; and using the annual global reference atmosphere defined in Recommendation ITU-R P.835. Based on this reference atmosphere, at the surface of the Earth, the dry air pressure is 1013.25 hPa, the temperature is 288.15 K, and the water vapour density is 7.5 g/m^3.

Losses due to geometrical spreading of energy (Free Space Path Loss) L_{sp} in dB units are calculated in terms of frequency f (GHz), and the propagation distance d (km) as follows:

$$L_{sp} = 92.45 + 20\log(f.d) \tag{1}$$

For a satellite at an altitude H and for an elevation angle φ, the propagation distance d can be obtained from equation (2).

$$d = \sqrt{(a\sin\varphi)^2 + 2aH + H^2} - a\sin\varphi \tag{2}$$

with a is the equivalent Earth radius which is equated to 6 371 km.

In addition to the above losses, there may also be losses due to either scattering from or absorption caused by precipitation.

Restricting FS links to low elevation angles may be an effective mitigation technique in limiting interference to EESS sensors, however any restrictions on the elevation angle of the FS stations would need to be a mandatory regulatory provision in order for this mitigation technique to be effective. Further complicating this issue is the fact that there are multiple types of EESS sensors in use, each with different beam-to-Earth characteristics. In some cases, these sensors look forward and in these cases, main beam alignment between even low angle fixed links and EESS sensors may be possible (though offset by higher atmospheric attenuation). These possible interference scenarios and their impact must be verified by sharing and compatibility studies.

For the FS and land mobile applications where low elevation angle transmission cannot be assured, alternative protection strategies must be used to achieve compatibility with the passive services identified in RR No. **5.565**. This may involve careful selection of bands for active service applications based on whether or not they are identified for EESS (passive) usage. Many of the bands identified for EESS (passive) usage under RR No. **5.565** have modest bandwidth between those identified bands. For instance, 286-296 GHz and 399-409 GHz are two bands of 10 GHz, which lie between bands identified for usage by EESS (passive). Thus these two bands may be practical for active use for types of systems where low elevation angle narrow beams antennas are not possible. In theory it may be possible to design multiple-input and multiple-output (MIMO) antennas that both address the link budgets of the intended use and also limit emissions at high elevation angles. However, this technology is not presently available and as a result spectrum access cannot be based on MIMO technology at this time.

Another method to protect NGSO EESS passive sensor operations that could encounter main beam to main beam coupling with terrestrial active services when they are at high elevation angles would be similar to techniques used in managing GSO/NGSO sharing for FSS communications satellites. This method would predict alignment events that would threaten the NGSO EESS satellite performance and modify the parameters of the terrestrial system during the time period of possible interference. This method however puts all the risk of method failure on the EESS (passive) and would require the use of a global database the details of which have not been defined. Furthermore, this method has not been successfully implemented in regards to any two services, any geographical scale, or any frequency range.

A final consideration for compatibility studies between the EESS (passive) and FS and land mobile service is the need to consider aggregate interference from multiple active systems deployed and radiating in the same bands. Such aggregation studies should consider both terrain and building obstruction of FS and LMS emissions.

7 Interference scenarios from land mobile and fixed service applications operating in the band 275-450 GHz to the passive service applications using spectrum identified in RR No. 5.565

According to RR No. **5.565**, the frequency bands 275-323 GHz, 327-371 GHz, 388-424 GHz and 426-442 GHz are identified for use by RAS applications while the bands 275-286 GHz, 296-306 GHz, 313-356 GHz, 361-365 GHz, 369-392 GHz, 397-399 GHz, 409-411 GHz, 416-434 GHz and 439-467 GHz are identified for use by EESS (passive) applications. The following sharing and compatibility studies have been addressed:

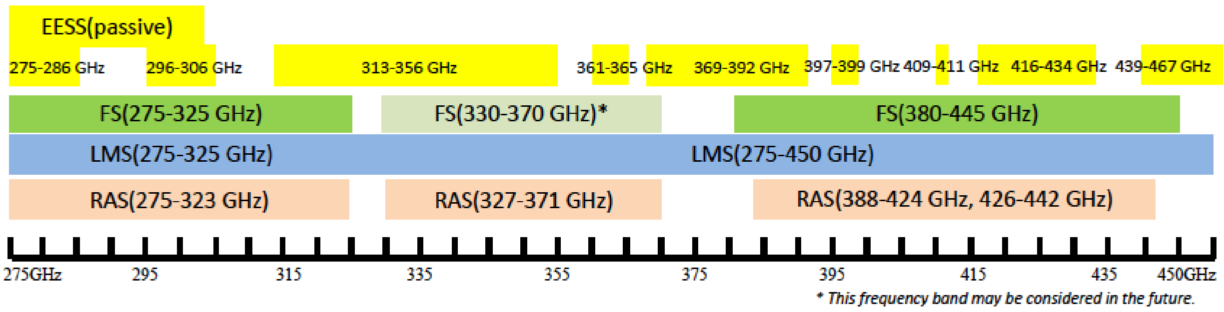
1 LMS application operating in the band 275-450 GHz with respect to the protection of EESS stations operating in the bands 275-286 GHz, 296-306 GHz, 313-356 GHz, 361-365 GHz, 369-392 GHz, 397-399 GHz, 409-411 GHz, 416-434 GHz and 439-467 GHz;

2 FS application operating in the band 275-450 GHz with respect to the protection of EESS stations operating in the bands 275-286 GHz, 296-306 GHz, 313-356 GHz, 361-365 GHz, 369-392 GHz, 397-399 GHz, 409-411 GHz, 416-434 GHz and 439-450 GHz;

3 FS application operating in the band 275-450 GHz with respect to the protection of RAS stations operating in the bands 275-323 GHz, 327-371 GHz, 388-424 GHz and 426-442 GHz.

FIGURE 9

Frequency bands considered in the sharing studies



7.1 Interference scenarios from LMS applications operating in the band 275-450 GHz to EESS (passive) and RAS

The two interference scenarios listed in Table 15 are shown in Fig. 10 and could be considered between LMS applications and passive services.

TABLE 15

Interference scenarios

Scenario	Interfering	Interfered with	Propagation model (See Annex 2)
A	LMS mobile terminal fixed station	EESS sensor	Rec. ITU-R P.619, Rec. ITU-R P.2108 (1), Rec. ITU-R P.2109 (2)
B	LMS mobile terminal fixed station	RAS station	Rec. ITU-R P.452, Rec. ITU-R P.2108 (3), Rec. ITU-R P.2109 (2)

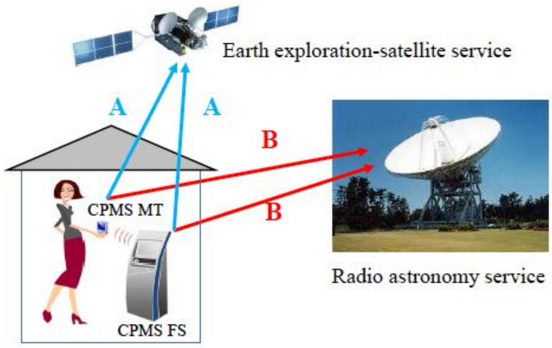
(1) The satellite-path clutter loss at 300-GHz band of 0 dB is extrapolated from this Recommendation.

(2) The building entry loss at 300-GHz band of 73 dB is extrapolated from this Recommendation.

(3) The terrestrial-path clutter loss at 300-GHz band of 47 dB is extrapolated from this Recommendation.

FIGURE 10

Illustration of interference scenarios between LMS application and passive services



7.2 Interference scenarios from FS applications operating in the band 275-450 GHz to the EESS (passive) and RAS

The two interference scenarios listed in Table 16 are considered between FS application (fronthaul/backhaul) and passive services.

TABLE 16

Interference scenarios

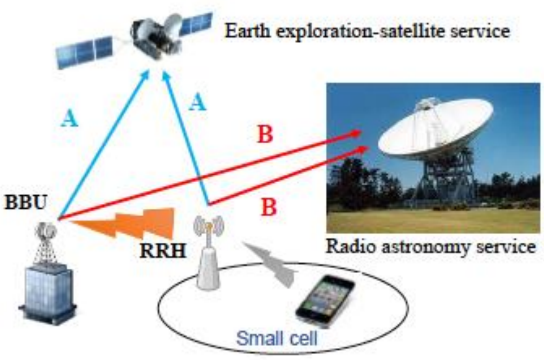
Scenario	Interfering	Interfered with	Propagation model (See Annex 2)
A	Fronthaul/Backhaul	EESS sensors	Rec. ITU-R P.619, Rec. ITU-R P.2108 (1)
B	Fronthaul/Backhaul	RAS station	Rec. ITU-R P.452, Rec. ITU-R P.2108 (2)

(1) The satellite-path clutter loss at 300-GHz band of 16 dB with an elevation angle of 12 degrees is extrapolated from this Recommendation.

(2) The terrestrial-path clutter loss at 300-GHz band of 47 dB is extrapolated from this Recommendation.

FIGURE 11

Illustration of interference scenarios between FS application and passive services



8 Sharing and compatibility studies related to EESS (passive)

8.1 Sharing and compatibility studies between LMS applications and earth exploration-satellite service (passive) applications

Sharing studies between LMS applications and EESS (passive) are detailed in Annex 4.

Study 3 analysed the interference potential that may result from LMS applications operating in the 275-450 GHz frequency range to the EESS (passive) systems. The approach taken in these analyses was to perform a single IFOV analysis of each type of passive sensor. This study found that compatibility without the need for mandatory regulatory provisions was achieved in the 275-296 GHz, 306-313 GHz, 320-330 GHz and 356-450 GHz frequency bands. This study also noted that in the band 275-286 GHz LMS applications were found to be problematic for both conical and nadir scanning sensors, however this band currently only used by limb sounders.

Study 4 concluded that the bands 275-296 GHz, 306-313 GHz, 319-332 GHz and 356-450 GHz can be used for LMS applications without any specific conditions. Indoor and outdoor use cases were also studied to identify possible frequency ranges for CPMS application in LMS.

8.2 Sharing and compatibility studies between FS applications and EESS (passive) applications

Several sharing and compatibility studies were performed to seek frequency bands that could be used by FS applications. These studies are detailed in Annex 4.

Study 2 is focused as on a single entry analysis of FS stations and an EESS (passive) for three different pointing scenarios across the 275-450 GHz frequency range, as on an aggregate analysis performed for FS elevation angle distributions ±20 and ±12 degrees. This study found that compatibility in the frequency bands 275-286 GHz, 318-334 GHz, 350-356 GHz, 361-365 GHz, 369-392 GHz, 397-399 GHz, 409-411 GHz, 416-434 GHz, and 439-450 GHz is possible.

Study 3 analysed the potential interference that may result from FS applications operating in the 275-450 GHz frequency range to the EESS (passive) systems. The approach taken in these analyses was to perform a single instantaneous field of view (IFOV) analysis of each type of passive sensor. This study found that compatibility was achieved in the 275-296 GHz, 306-313 GHz, 320-330 GHz and 356-450 GHz frequency bands. This study also noted that in the band 275-286 GHz FS applications were found to be problematic for both conical and nadir scanning sensors, however this band currently only used by limb sounders.

Study 4 provides the aggregate analysis in the frequency range 275-450 GHz. This analysis evaluated the compatibility between FS station and EESS (passive) sensors. This study concluded that FS stations would not interfere with EESS (passive) sensors in the frequency bands 275-296 GHz, 306-313 GHz, 318-336 GHz and 348-450 GHz. Although the frequency range 275-450 GHz is split into four frequency segments, a contiguous band of 50 GHz is achievable.

Study 5 concluded that the following bands currently identified for EESS (passive) in RR N° **5.565** cannot be used by the FS: 296-306 GHz, 313-320 GHz and 331-356 GHz. In the remaining parts of the 275-450 GHz range, FS usage can be envisaged. These bands would be enough to accommodate FS spectrum requirements of 50 GHz.

8.3 Summary of the sharing and compatibility studies related to EESS (passive)

Table 17 summarizes the bands proposed for use for FS/LMS applications by Studies 2, 3, 4 and 5. The studies conclude that certain frequency bands could be used by land-mobile and fixed services. While each study contains slightly differing results (as shown in the Table), consensus among all the studies is that the following frequency bands could be used by FS/LMS applications without specific conditions, while maintaining the protection of the passive services:

– FS/LMS applications: 275-296 GHz, 306-313 GHz, 320-330 GHz and 356-450 GHz;

These results do not include compatibility with the radio astronomy service, which is addressed in the following section.

TABLE 17

Summary of the study results

Study	Application Service	Compatible Bands for FS/LMS (where no specific conditions to protect EESS (passive) are necessary)			
		Band 1 (GHz)	Band 2 (GHz)	Band 3 (GHz)	Band 4 (GHz)
2	FS & LMS	275-296	306-313	318-333	356-450
3	FS & LMS	275-296	306-313	320-330	356-450
4	FS & LMS	275-296	306-313	319-332	356-450
5	FS & LMS	275-296	306-313	318-333	356-450

9 Sharing and compatibility studies related to RAS

9.1 Sharing and compatibility studies between LMS application and radio astronomy service

No sharing and compatibility studies between LMS applications and the radio astronomy service were conducted. However, Report ITU-R RA.2189-1 results are agnostic to the type of service as this Report only considers the power level of a single transmitter and its separation from the RAS site. Report ITU-R RA.2189-1 concludes that sharing studies at specific geographic locations are needed on a case-by-case basis. For LMS applications, aggregate interference should be considered.

9.2 Sharing studies between FS applications and radio astronomy service

Several sharing and compatibility studies were performed to seek frequency bands that could be used by FS applications. These studies are detailed in Annex 5.

Study 1 contains two examples under conditions typical of those encountered in the vicinity of sites used for radio astronomical observations. The two geometries studied were: FS link and RAS on the same flat plane, with the FS link azimuth angle and power varying, and FS link and RAS at different heights, with the FS beam fixed at the azimuth of the RAS operation and with its distance and elevation angle varying. Three frequencies are used in the studies: 275 GHz, 345 GHz and 412 GHz. These studies concluded that separation distances, as well as azimuthal and elevation avoidance angles may be needed to protect RAS sites, as atmospheric losses alone are not sufficient to ensure compatibility.

Study 2 contains several calculations of necessary separation distances when considering the FS station and the RAS site at a variety of altitudes. The study indicated that separation distances of 150 km are needed, and minimum separation distances are achieved at atmospheric absorption peaks. These distances may be reduced if clutter loss is accounted for.

9.3 Summary of the sharing and compatibility studies related to RAS

Compatibility studies between the RAS and FS applications concluded that atmospheric attenuation alone, independent of free-space losses, at 275-450 GHz is not sufficient to provide compatibility between FS and RAS operations in the absence of other considerations. In the bands identified for use by RAS applications in RR No. **5.565** (275-323 GHz, 327-371 GHz, 388-424 GHz and 426-442 GHz), separation distances and/or avoidance angles between RAS stations and FS stations should be considered depending on the deployment environment of FS stations.

For the case of operations at the same geographic elevation, it is necessary that FS beams do not point too nearly toward an RAS site. The size of the avoidance angle will depend on the details of the actual FS beam pattern that is used in any situation, among other variables. For the case of high-elevation RAS operations in direct line of sight of FS operations at much lower elevations, FS beams may be directed in azimuth toward the RAS site at frequencies near the higher end of the band or at sufficiently horizontal separations, but should be studied on a case by case basis depending on the power level of the transmitter.

Scenarios involving aggregate interference from multiple-entry FS deployments will require detailed modelling based on the details of each situation and must be evaluated on a case by case basis.

Annex 1

TABLE A1-1

Bands of interest for EESS (passive) between 275 and 450 GHz (extracts from Report ITU-R RS.2194)

Frequency band(s) (GHz)	Total bandwidth required (MHz)	Spectral line(s) (GHz)	Measurement			Typical scan mode	Existing or planned instrument(s)	Supporting information
			Meteorology – Climatology	Window (GHz)	Chemistry			
275-285.4	10 400	276.33 **(N_2O)**, 278.6 **(ClO)**		276.4-285.4	N_2O, ClO	Limb		**Chemistry** (275-279.6), **Window** (276.4-285.4)
296-306	10 000	Window for 325.1, 298.5 **(HNO_3)**, 300.22 **(HOCl)**, 301.44 **(N_2O)**, 303.57 **(O_3)**, 304.5 **($O^{17}O$)**, 305.2 **(HNO_3)**,	Wing channel for temperature sounding	296-306	OXYGEN, N_2O, O_3 , $O^{17}O$, HNO_3, HOCl	Nadir, Limb		**Window** (296-306), **Chemistry** (298-306)
313.5-355.6	42 100	313.8 **(HDO)**, 315.8, 346.9, 344.5, 352.9 **(ClO)**, 318.8, 345.8, 344.5 **(HNO_3)**, 321.15, 325.15 **(H_2O)**, 321, 345.5, 352.3, 352.6, 352.8 **(O_3)**, 322.8, 343.4 **(HOCl)**, 345.0, 345.4 **(CH_3Cl)**, 345.0 **($O^{18}O$)**, 345.8 **(CO)**, 346 **(BrO)**, 349.4 **(CH_3CN)**, 351.67 **(N_2O)**, 354.5 **(HCN)**,	WATER VAPOUR PROFILING, CLOUD, Wing channel for temperature sounding	339.5-348.5	H_2O, CH_3Cl, HDO, ClO, O_3 , HNO_3, HOCl, CO, $O^{18}O$, HCN, CH_3CN, N_2O, BrO	Nadir, Conical, Limb	STEAMR (PREMIER), CLOUDICE, MWI (ICI), GOMAS, GEM	**Water vapour line at 325.15** (314.15-336.15, BW: 3 GHz, max. offset: 9.5 GHz), **Cloud Measurements** (331.65-337.65, 314.14-348, 339-348, 314.14-317.15, 320.45-324.45, 325.8-329.85, 336-344, 339-348), **CLOUDICE** (314.15-336.15), **MWI (ICI)** (313.95-336.35) **Window** (339.5-348.5), **GEM Chemistry** (342-346), **STEAMR (4) (PREMIER) Chemistry** (310.15-359.85)
361.2-365	3 800	364.32 **(O_3)**	Wing channel for water vapour profiling		O_3	Nadir, Limb	GOMAS	**GOMAS Water vapour** (361-363), **Chemistry** (363-365)

TABLE A1-1 (*end*)

Bands of interest for EESS (passive) between 275 and 450 GHz (extracts from Report ITU-R RS.2194)

Frequency band(s) (GHz)	**Total bandwidth required (MHz)**	**Spectral line(s) (GHz)**	**Measurement**			**Typical scan mode**	**Existing or planned instrument(s)**	**Supporting information**
369.2-391.2	22 000	380.2 (**H_2O**)	WATER VAPOUR PROFILING			Nadir, Limb	GEM, GOMAS	**Water vapour line** (369.2-391.2, BW: 3 GHz, max. offset: 9.5 GHz), **GEM Water vapour sounding** (379-381), **Water vapour profiling** (371-389), Polar-orbiting and GSO satellites (FY4) for precipitation over snow-covered mountains and plains (near 380) **GOMAS** (370.2-390.2)
397.2-399.2	2 000		WATER VAPOUR PROFILING				GOMAS	**GOMAS** (397.2-399.2)
409-411	2 000		Temperature sounding			Limb		
416-433.46	17 460	424.7 (**O_2**)	OXYGEN, Temperature profiling			Nadir, Limb	GEM, GOMAS	**Oxygen line** (416.06-433.46, BW: 3 GHz, max. offset: 7.2 GHz), **GEM Oxygen** (416-433) **GOMAS** (420.26-428.76)
439.1-466.3	27 200	442 (**HNO_3**), 443.1, 448 (**H_2O**), 443.2 (**O_3**),	WATER VAPOUR PROFILING, CLOUD	458.5-466.3	O_3, HNO_3, N_2O, CO	Nadir, Limb, Conical	MWI (ICI), CLOUDICE	**Water line** (439.3-456.7, BW: 3 GHz, max. offset: 7.2 GHz), **Cloud measurements** (452.2-458.2, 444-447.2, 448.8-452, 459-466), **CLOUDICE** (439.3-456.7), MWI (ICI) (439.1-456.9), **Chemistry** (442-444), **Window** (458.5-466.64),

(4) Due to the instrument needs for the tuning of the local oscillator in order to achieve optimal measurement accuracy, the frequency band indicated for this instrument (STEAMR) exceeds the one shown in the corresponding first column.

Annex 2

Extrapolation of building entry loss and clutter loss from Recommendations ITU-R P.2108 and ITU-R P.2109 for sharing and compatibility studies

This Annex estimate the median building entry loss (BEL) and clutter loss at 300-GHz band using extrapolation of the results of Recommendations ITU-R P.2109 and ITU-R P.2108. Figure A2-1 shows the extrapolated building loss at 300-GHz band of about 73 dB in the condition of thermally-efficient building and 27.7 dB for traditional buildings without considering additional loss at the building façade for simplicity. However while the median value of BEL can be extrapolated from the model, the entire distribution of the BEL would be needed in order to utilize this information in the sharing studies; in its present form the BEL model can only give BEL distributions for frequencies up to 100 GHz. In the future, further detailed information may be available about building loss on these frequencies, avoiding the need to extrapolate values.

Figure A2-2 shows the extrapolated median clutter loss for the satellite path at p=50% with the different elevation angles. However the median value of clutter loss cannot be used in the sharing and compatibility studies; the entire distribution of the Clutter loss values for a given frequency and elevation would need to be used. This distribution can be calculated from the Clutter model. Since the clutter loss for the satellite path with an elevation angle of 90 degree is close to zero, the clutter loss is not added for the studies between LMS application and EESS (passive). Figure A2-3 shows the extrapolated clutter loss for terrestrial paths using Recommendation ITU-R P.2109.

FIGURE A2-1

Extrapolation of median building entry loss using Recommendation ITU-R P.2109

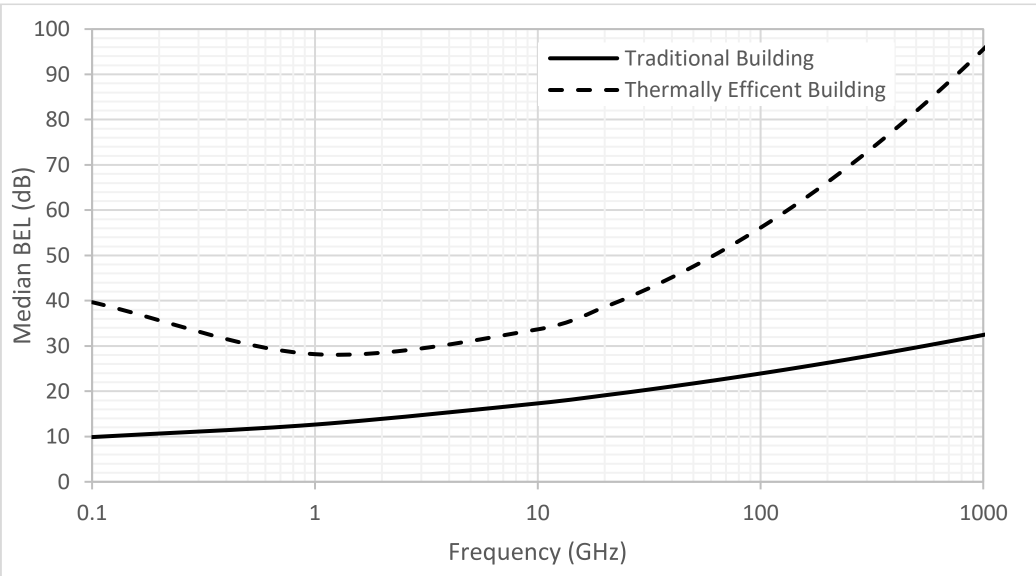
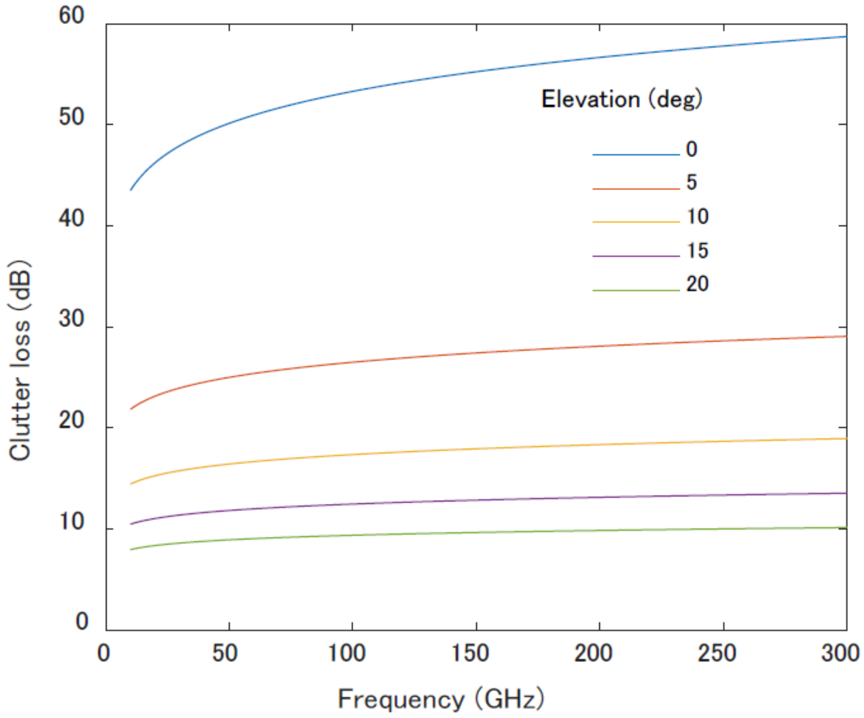


FIGURE A2-2

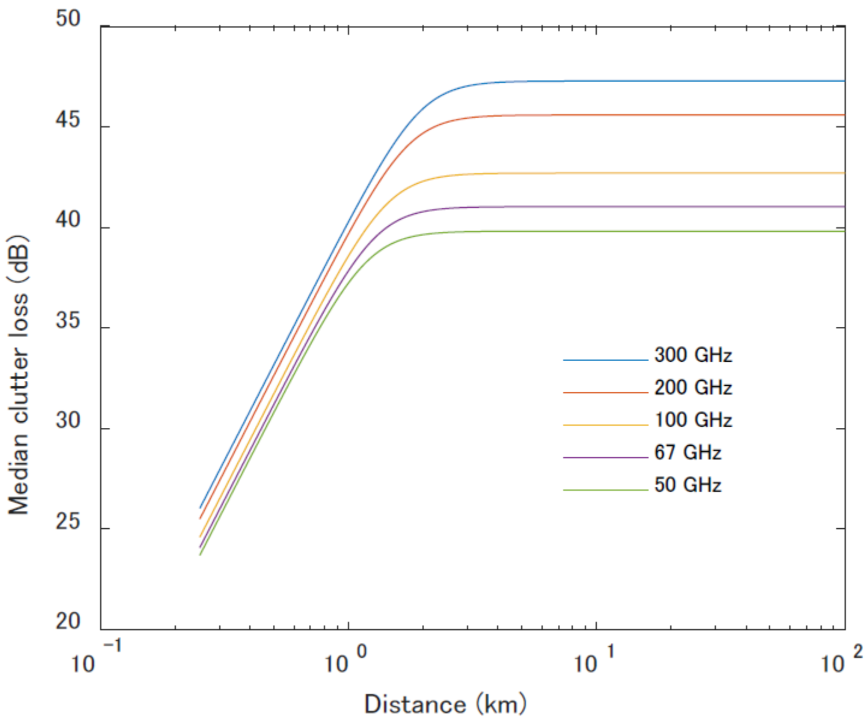
Extrapolation of median clutter loss (p=50%) for the satellite path using Recommendation ITU-R P.2108



NOTE – The entire distribution of the Clutter model would need to be used in the sharing and compatibility analysis.

FIGURE A2.3

Clutter loss for the terrestrial path extrapolated using Recommendation ITU-R P.2108



Annex 3

Measurement results of radiation pattern of antenna at 300 GHz

This Annex provides the antenna radiation pattern used in some studies in Annex 4.

FIGURE A3-1

Measured characteristics of 30-dBi and 15-dBi antennas

a) 30-dBi Horn antenna **b) 15-dBi CPMS antenna**

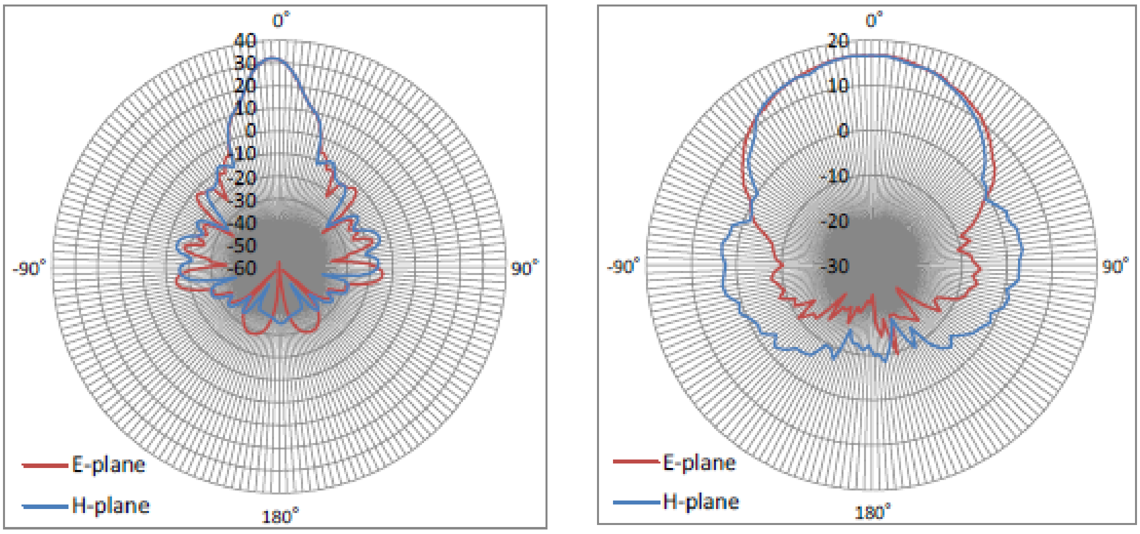
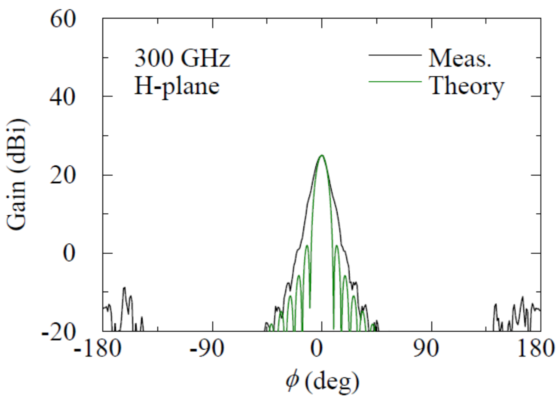


FIGURE A3-2

Measurement results of horn antenna pattern whose antenna gain is 25 dBi

a) H-plane



b) E-plane

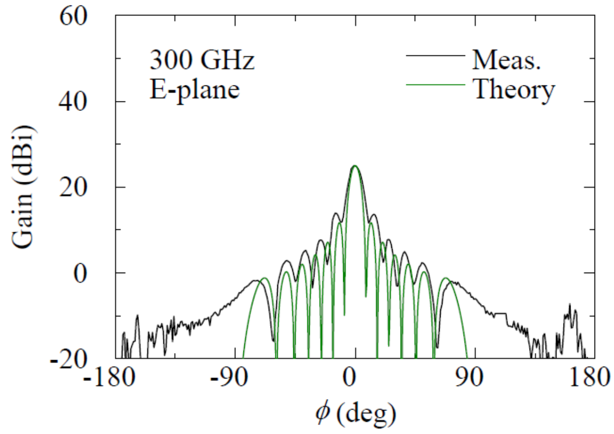


FIGURE A3-3

Measured characteristics of offset parabola antenna with a maximum gain of 49 dBi

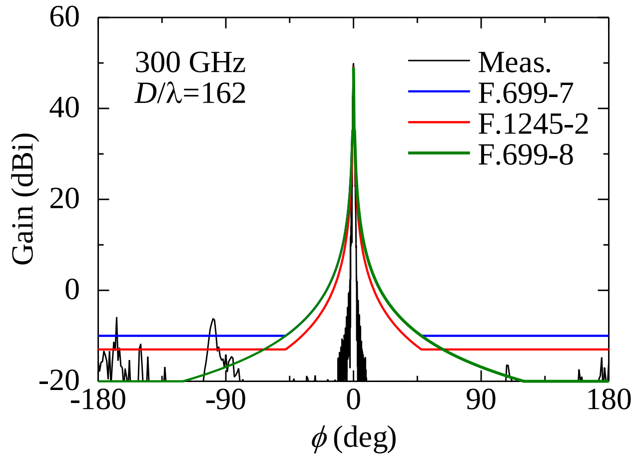
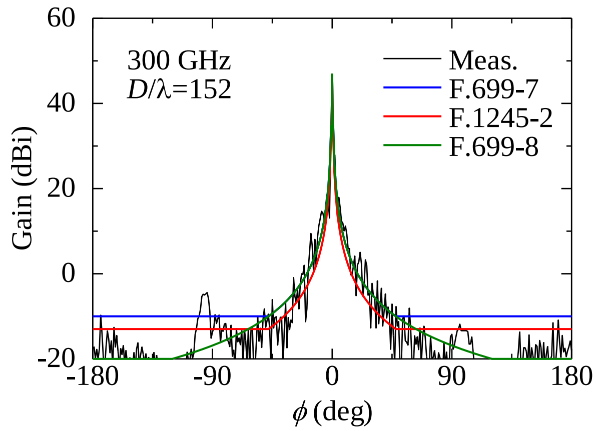


FIGURE A3-4

Measured characteristics of cassegrain antenna with a maximum gain of 47 dBi



Annex 4

Sharing studies between LMS and FS applications and Earth exploration satellite service

A4.1 Introduction

This Annex provides the results of four sharing studies (Studies 2, 3, 4 and 5) between EESS (passive) and FS and LMS applications in the bands identified for EESS (passive) in the 275-450 GHz frequency range.

The frequency bands under study are given in RR No. **5.565**, namely: 275-286 GHz, 296-306 GHz, 313-356 GHz, 361-365 GHz, 369-392 GHz, 397-399 GHz, 409-411 GHz, 416-434 GHz and 439-467 GHz.

It should be noted that due to the fact that the bands 275-286 GHz and 409-411 GHz are limited to the use of EESS (passive) limb sounders, they are already assumed, by principle, to be used for land-mobile and fixed services applications.

It can also be noted that Study 1 depicts the initial static analysis of sharing between FS and EESS (passive) and was performed before the FS characteristics were finalised. It was however felt as valuable to keep it as a reference study.

A4.2 Study 1: Static analysis between FS/LMS and EESS (passive)

This study considers a static analysis between an FS/LMS station pointing directly toward an EESS (passive) satellite and calculates the maximum single entry interference received by the EESS (passive) sensor.

A4.2.1 Maximum allowable single entry emission levels

When considering the emissions from a FS/LMS source at a given point on Earth, composite attenuation at the EESS (passive) sensor can be calculated by considering three factors:

– The free space attenuation Att_{FS}, controlled by the slant path distance between the satellite and the point on Earth;

– The gaseous attenuation Att_{GAS} (see Recommendation ITU-R P.676), controlled by the elevation at which the satellite is seen from the point on Earth;

– The sensor antenna relative gain G_{discri}, controlled by the angle at which the point on Earth is seen from the satellite, compared to the pointing angle of the sensor.

It is noted that the attenuation of a signal originating from the Earth's surface and emitted towards an EESS (passive) sensor can be greater, on a time varying basis, than the sum of the composite attenuation elements listed above when atmospheric refraction is taken into consideration. However, it should be noted that the transmission path from an emitter on the surface of the Earth directed towards an EESS (passive) sensor is as likely to be refracted towards the EESS (passive) sensor as it is to be refracted away from the EESS (passive) sensor. As a result, atmospheric refraction has a neutral impact on the results of this static analysis and can also be neglected in conducting dynamic analyses that may need to be done.

The received interference at the satellite sensor receiver from a single terrestrial transmitter (with radiated power P in the direction of the satellite) at a given point on Earth is then:

$$I = P - Att_{FS} - Att_{GAS} + G_{discri} = P - Att_{composite}$$

where:

$$Att_{composite} = Att_{FS} + Att_{GAS} - G_{discri} = \text{“Composite attenuation”}.$$

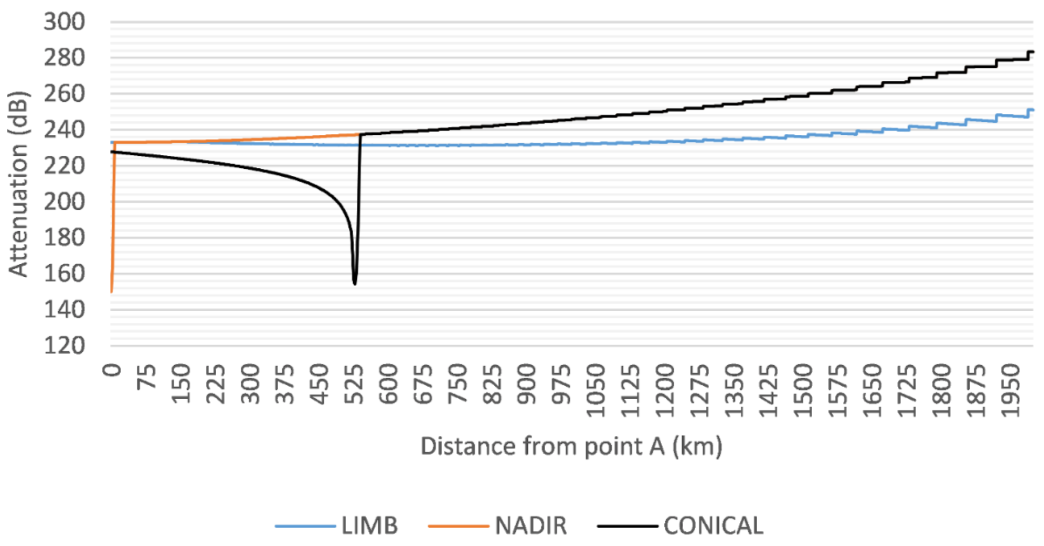
Taking the example of the 296-306 GHz band, Fig. A4-1 provides the results of composite attenuation calculations between a point on the Earth and the three types of EESS passive sensors.

This analysis starts at point A (nadir of the satellite) up to point B, 2 000 km from A, this distance represents the farthest an interferer could be from the nadir of a satellite at 817 km altitude when considering the measurement area prescribed by Recommendation ITU-R RS.2017.

– Satellite altitude = 817 km
– Satellite sensor antenna gain = 60 dBi
– Satellite sensor antenna pattern (Recommendation ITU-R RS.1813)
– Gas attenuation at 301 GHz (Recommendation ITU-R P.676, Annex 2 (simplified model))
– Pointing altitude for Limb sensor = 25 km
– Nadir angle for conical sensor = 32.2°.

FIGURE A4-1

Composite attenuation of FS/LMS emissions into EESS (passive) for the modes N, L, and C



Given the assumptions above, one can note from this Figure that:

– The composite attenuation when considering Limb sensors is always between 230 and 250 dB;
– The composite attenuation when considering Nadir and Conical sensors reaches a minimum at the sensor antenna incidence angle at Earth values of 150 dB and 154 dB respectively.

The composite attenuation will increase as a function of frequency and with increasing distance from nadir (i.e. lower elevations angles with respect to the location of the device and the EESS sensor). However, since the EESS (passive) sensors are deployed on NGSO satellites the elevation angle of the device with respect to the sensor will change as the satellite orbits and the overall interference will be dominated by the devices located near where EESS beam intersects the earth at the indecent angle of the sensor.

In practice, the total received interference to the EESS (passive) sensor will be the sum of all interference calculated for all sources of interference within the visibility of the satellite, including sources of interference received by the sensor through its antenna sidelobes. Considering the high level of composite attenuation calculated for the Limb sensors, the experience shows that for the calculation of the main beam is sufficient to describe the interference that would occur to Nadir and Conical sensors, as the interference received through the sidelobes can be neglected due to the level of antenna discrimination available.

On this basis, considering typical design of EESS (passive) sensors provided in Table A1-1, the following Table provides the calculation of the allowable single entry FS or LMS emission levels directed towards the EESS (passive) sensor in a reference area that would be necessary to ensure protection of EESS (passive) sensors in the 296-306 GHz band.

It must be recognized that any sharing conclusion between the EESS (passive) and the FS and LMS in the 275-450 GHz band has to include consideration of the aggregate interference caused by the FS and LMS in a EESS (passive) footprint (reference area) in conjunction with consideration of the Recommendation ITU-R RS.2017 data availability criteria over the prescribed measurement area would then need to be considered. Table A4-1 does not consider aggregate interference caused by the FS and LMS, nor does it take into account the data availability criteria.

TABLE A4-1

Maximum allowable single entry FS/LMS emission levels directed toward the EESS (passive)[6]

Parameter	Unit	Idx	Nadir	Conical	Limb
Satellite orbit	km		817	817	817
Antenna incidence angle at Earth	°		0	53	N/A
Slant path distance (centre of the footprint)	km		817	991	
Free Space losses, Att_{FS}	dB	a	200.3	201.9	
Atmospheric losses (P.676), Att_{GAS}	dB	b	9.8	12.2	
Sensor Antenna gain	dBi	c	60	60	
Composite attenuation, $Att_{composite}$	dB	d = a + b – c	150.1	154.1	230 to 250
Aggregate protection criteria (RS.2017)	dBW	e	–160	–160	–194
Reference bandwidth	MHz		200	200	3
Apportionment of the protection criteria (50% FS and 50% LMS)	dB	f	3	3	3

6 The maximum allowable single entry FS/LMS emission levels that can be directed toward the EESS (passive) is based on the worst case interference scenario that can be realized between the FS/LMS and the EESS (passive) sensor.

TABLE A4-1 (*end*)

Parameter	Unit	Idx	Nadir	Conical	Limb
Maximum single entry emission level directed toward EESS (passive) in the reference area	dBW/200 MHz	= e – f + d	–12.9	–8.9	33 to 53 dBW/ 3 MHz
reference area (footprint size for nadir and conical, visibility for limb)	km²		10(N)/20(C)	10(N)/20(C)	29.5 M

A4.2.2 Maximum single entry emission levels of FS systems

The FS parameters in the 275-450 MHz range are given in Report ITU-R F.2416 and reproduced in Table 7 of this Report.

Taking into account a 0 dBW FS transmitter e.i.r.p., Table A4-2 provides calculations of FS e.i.r.p. density (dBW/200 MHz) for the two extreme FS antenna gain values and all proposed bandwidths from Table 7 and Table A4-2 above.

TABLE A4-2

FS e.i.r.p. density (dBW/200 MHz)

FS bandwidth (GHz)	Bandwidth factor vs 200 MHz	e.i.r.p. density (dBW/200 MHz) for 24 dBi antenna	e.i.r.p. density (dBW/200 MHz) for 50 dBi antenna
2.16	–10.3	13.7	39.7
4.32	–13.3	10.7	36.7
8.64	–16.4	7.6	33.6
12.96	–18.1	5.9	31.9
17.28	–19.4	4.6	30.6
25.92	–21.1	2.9	28.9
51.84	–24.1	–0.1	25.9
69.12	–25.4	–1.4	24.6

The results of Table A4-2 in combination with the results of Table A4-1 show that the FS e.i.r.p. density in 200 MHz exceeds the allowable single entry FS emission levels by:

- Conical instruments (limit of –8.9 dBW/200 MHz):
  - 7.5 to 22.6 dB (for 24 dBi antenna);
  - 33.5 to 48.6 dB (for 50 dBi antenna),
- Nadir instruments (limit of –12.9 dBW/200 MHz):
  - 11.5 to 26.6 dB (for 24 dBi antenna);
  - 37.5 to 52.6 dB (for 50 dBi antenna).

A4.2.3 Summary of Study 1

This study indicates that the emissions of a single FS/LMS transmitter pointing directly at an EESS (passive) satellite with a nadir or conical sensor would exceed the interference threshold level. This demonstrates that when only considering the single entry emission characteristics of the FS/LMS and the composite attenuation sharing between FS/LMS and EESS (passive) nadir and conical instruments in the 296-306 GHz (and also in all the other bands in the 275-450 GHz range used by nadir and conical instruments), sharing could be problematic. Consideration of the aggregate interference resulting from the deployment density of both the LMS and FS has not been included in this initial study. Path loss varies significantly with frequency and elevation angle and generally increases at higher frequencies and lower elevations angles. As such, further analysis should consider the operational elevation angles of such FS systems.

In addition, aggregate scenario analysis will need to be addressed, in further studies of Limb sensors. As a result, the description of the FS deployment scenarios including densities of equipment per km² in various environments (rural, suburban and urban) is also needed.

Sharing between FS and EESS (passive) in the 275-450 GHz range will require further studies, considering both single entry and aggregate scenarios with the different EESS (passive) sensors types and frequency ranges.

However, to formulate the final conclusions the clarifications about the following items are needed:

– The description of the FS elevation distribution expected in the band above 275 GHz;

– The description of the FS antenna pattern(s);

– The description of the FS deployment scenarios (densities of equipment per km²) in various environments (Rural, suburban and urban).

Similar elements would also be required to address the sharing between LMS and EESS (passive).

Finally, compatibility of EESS (passive) in adjacent bands adjacent to proposed FS and LMS operations will have to be considered in particular when dealing with very large bandwidth systems. To that end, information about the relevant FS and LMS emission masks is also needed.

A4.3 Study 2: Assessment of FS interference to EESS (passive)

A4.3.1 Assessment of single entry FS interference to EESS (passive)

This study presents a static analysis between an FS station and an EESS (passive) satellite for three different pointing scenarios across the 275-450 GHz frequency range.

The three scenarios considered for this analysis are shown in Fig. A4-2. Scenario 1 is when the maximum of FS antenna gain coincides with maximum of EESS satellite antenna working in nadir mode. Scenario 2 is when the maximum of FS antenna gain coincides with maximum of EESS satellite antenna working in conical scan mode. Scenario 3 – FS station using typical elevation angles according to Table 7 of the main body of the Report, i.e. some antenna discrimination is assumed.

FIGURE A4-2

Interference scenarios between single FS transmitter and EESS

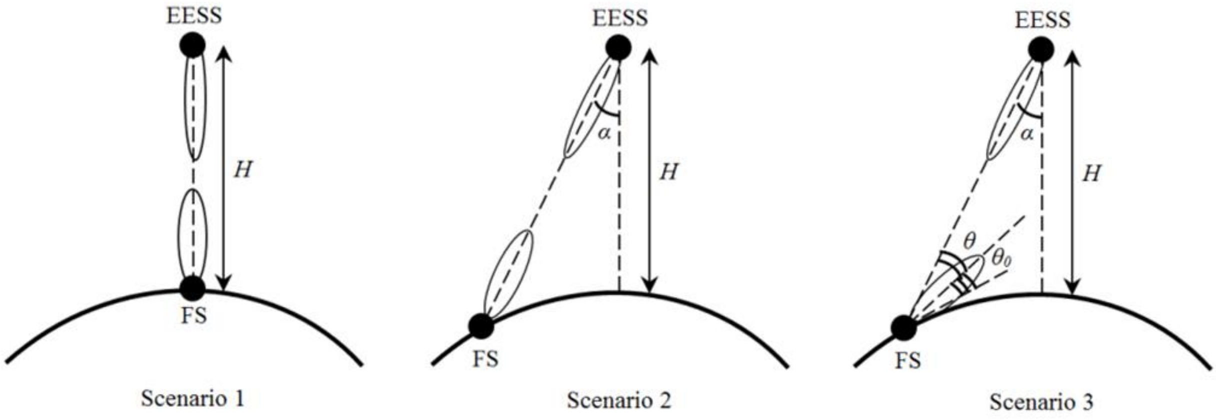


TABLE A4-3

FS Parameters Used in Single Entry Study

	Scenario 1	**Scenario 2**	**Scenario 3**
FS station e.i.r.p. (dBm)	20	20	20
FS gain toward EESS satellite	24/50	24/50	10.8/–2.4
FS bandwidth (GHz)	2/25	2/25	2/25
EESS altitude (km)	400	400	400
EESS pointing angle α (degree)	0	45	45

Figures A4-3 through A4-5 contain the single entry interference levels in the frequency range 275-450 GHz. For these Figures, the frequencies that are highlighted in blue are used only by EESS (passive) limb sounders. The maximum allowable interference level is indicated with dashed red line.

FIGURE A4-3

Interference between FS station and EESS satellite working in nadir mode (Scenario 1)

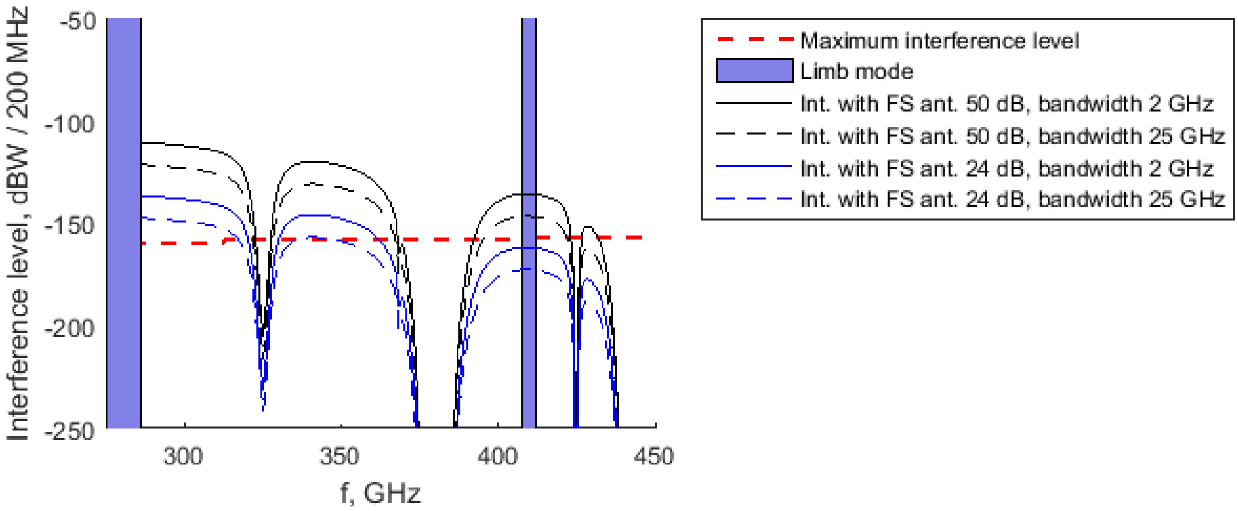


FIGURE A4-4

Interference between FS station and EESS satellite working in conical scan mode (Scenario 2)

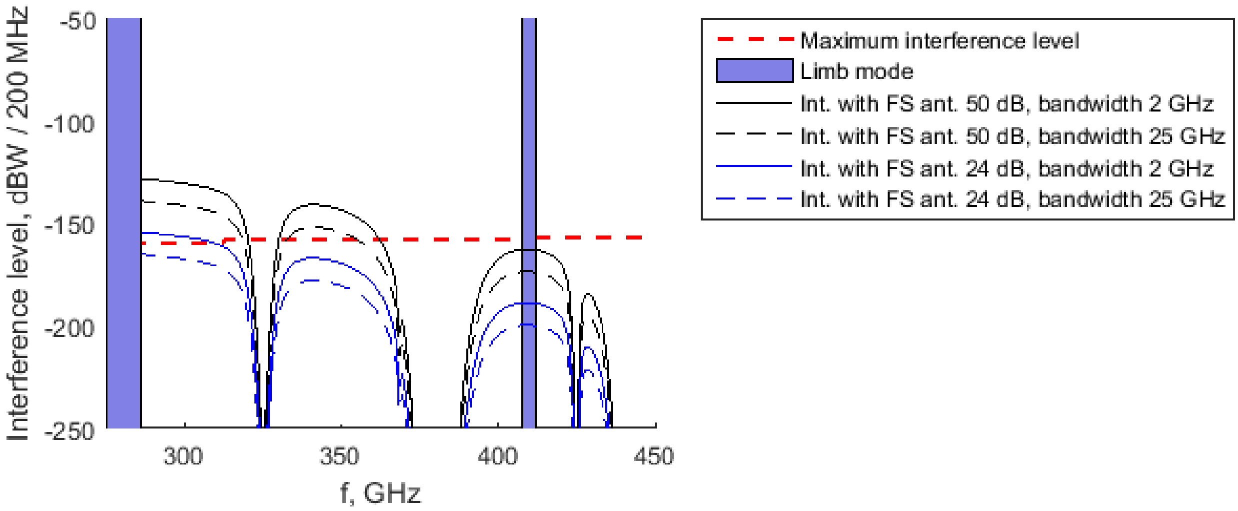


Figure A4-5 contains the interference analysis between and FS station and a conical EESS sensor for Scenario 3, similar to Fig. A4-4 but for the FS station at a 20 degrees elevation angle ($\theta_0 = 20°$), i.e. with antenna discrimination angle 21 degrees (according to equation (1)).

$$\theta = \cos^{-1}\left(\frac{(a+H)\sin\alpha}{a}\right) - \theta_0, \qquad (1)$$

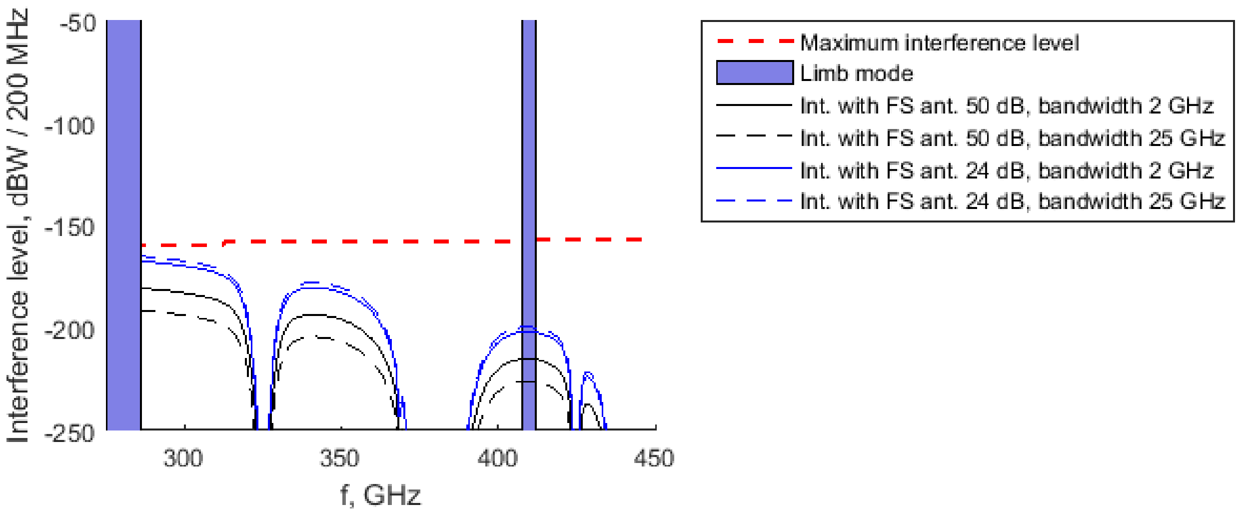
where:

- a: Earth radius
- H: altitude of the EESS satellite
- α: angle from the nadir direction
- θ_0: FS elevation angle.

The antenna gain in the direction towards the satellite is then –2.4 dBi for 50 dBi antenna and 10.8 dBi for 24 dBi antenna according to the reference radiation pattern from the current version of Recommendation ITU-R F.699.

FIGURE A4-5

Interference between FS station and EESS satellite working in conical scan mode (Scenario 3) with antenna discrimination



The single entry interference results for three considered scenarios permit to make a preliminary conclusion about the possibility to provide sharing between FS and EESS (passive) in a number of frequency bands due to the propagation conditions.

A4.3.2 Assessment of aggregate FS interference to EESS (passive)

For aggregate interference calculation the frequencies 399 GHz, 416 GHz and 429 GHz were chosen.

The following parameters of EESS satellite were used: beamwidth – 0.64 degrees, EESS satellite antenna gain – 60 dBi, satellite altitude – 400 km.

The following FS system parameters were used: antenna gain of 24 and 50 dBi (reference radiation patterns according to the current version of Recommendation ITU-R F.1245), bandwidth of 2 GHz, transmitter power of 20 dBm. The FS density was taken as in § 5.2.1 (the same as expected IMT-2020 density). Elevation angle distribution was assumed as ±20 degrees (according to Table 7) and ±12 degrees. The percentage of simultaneously working stations is 100%, all are working on the same frequency.

On Fig. A4-6 the calculation results for three frequencies and two elevation angle distributions (±20 degrees and ±12 degrees) are presented for 24 dBi FS antenna and on Fig. A4-7 – for the 50 dBi FS antenna.

According to the current version of Recommendation ITU-R F.1245, for 50 dBi antenna the gain in the direction orthogonal to the maximum is –13 dBi, and for 24 antenna it is –7.07 dBi.

FIGURE A4-6

Aggregate FS interference with 24 dBi FS antenna gain to EESS satellite working in nadir mode

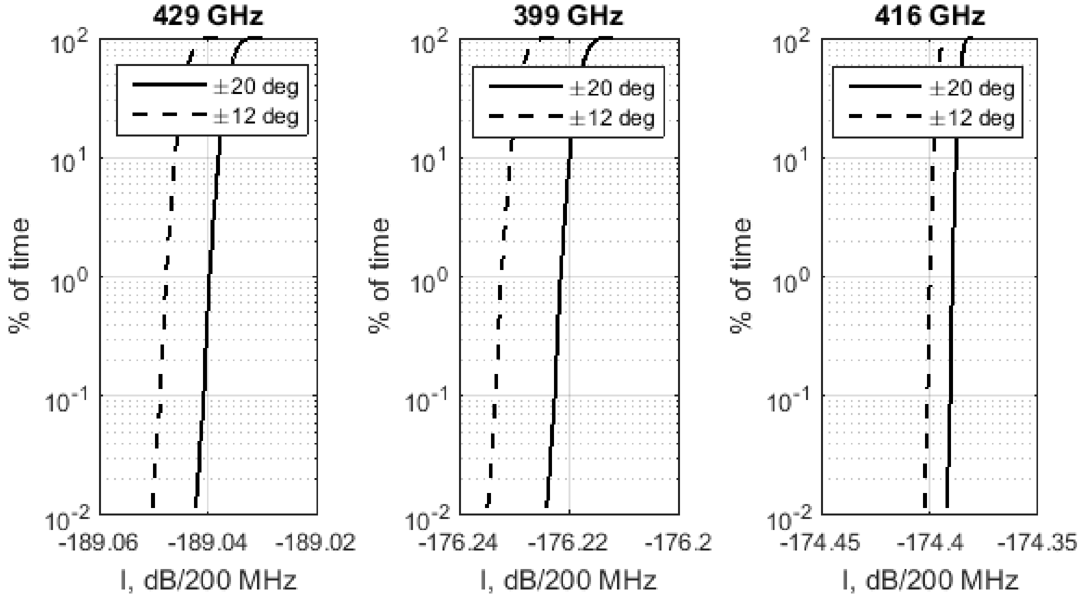
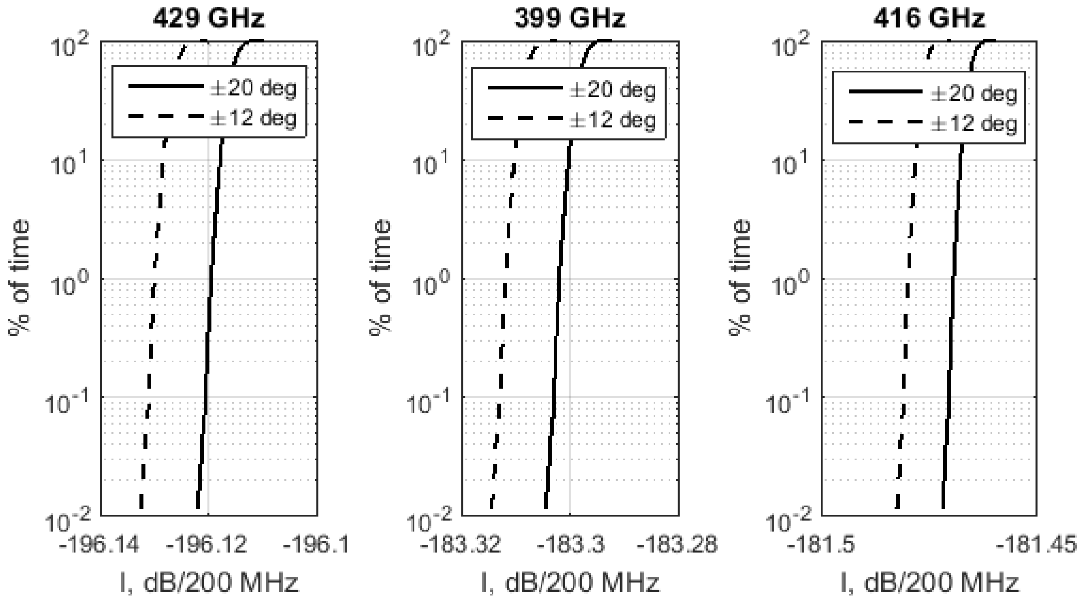


FIGURE A4-7

Aggregate FS interference with 50 dBi FS antenna gain to EESS satellite working in nadir mode



According to Table 12 in the main body of this Report, the maximum interference levels for these frequencies have the following values:

429 GHz: –157 dBW/200MHz,

399 GHz: –158 dBW/200MHz,

416 GHz: –157 dBW/200MHz.

Thus for both FS antenna the interference level is not exceeded for chosen frequencies for all percentages of time.

Assessment of the frequency bands where the sharing is possible can be performed based on Figs A4-8 and A4-9, showing the approximate values of aggregate interference levels taking into account bands identified for EESS (passive). These values were calculated as:

$$I_{aggr} = I_{single}(\theta_0 = 0) + 10\lg N \qquad (2)$$

where N is the number of FS stations.

FIGURE A4-8

Approximate aggregate FS interference to EESS satellite (passive) working in nadir mode with FS antenna gain 24 dBi

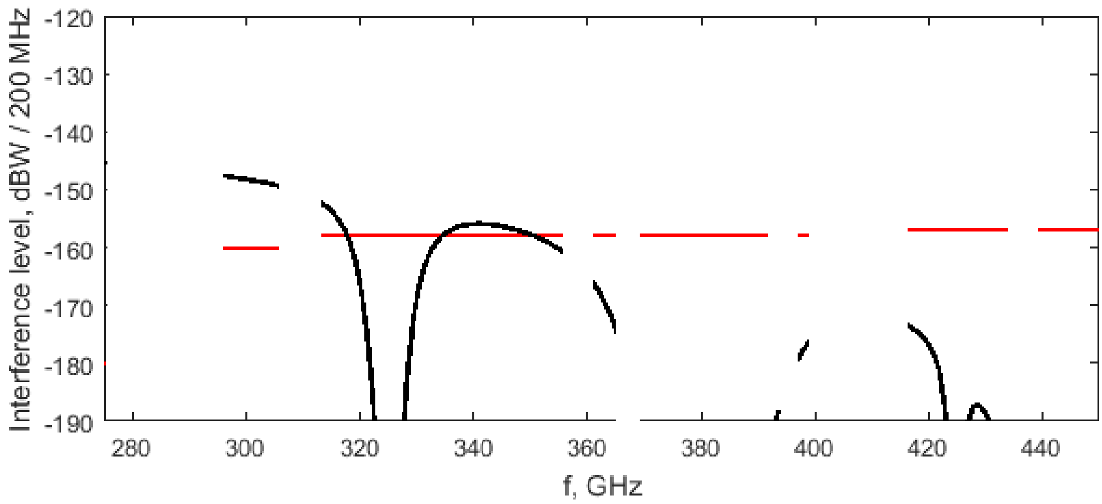
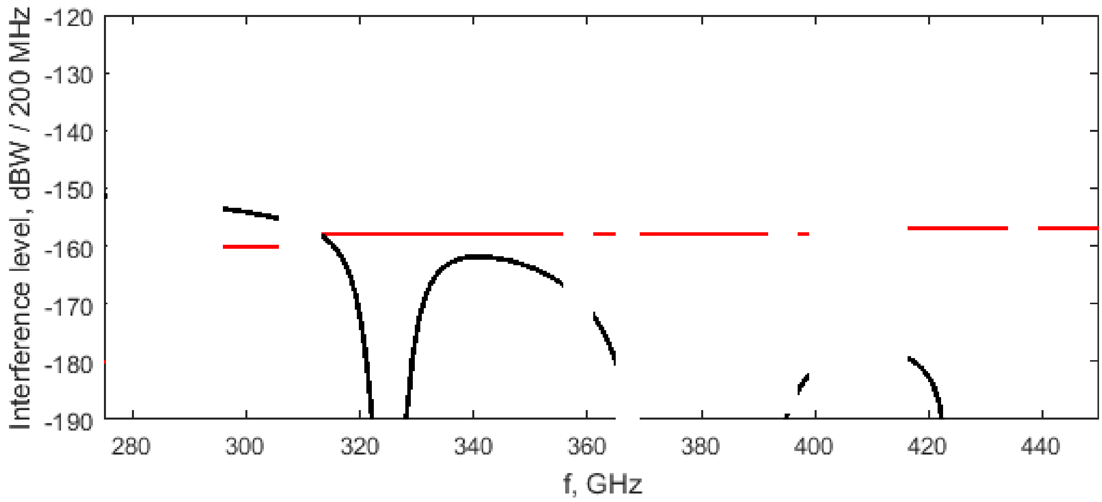


FIGURE A4-9

Approximate aggregate FS interference to EESS satellite (passive) working in nadir mode with FS antenna gain 50 dBi



Based on Figs A4-8 and A4-9, in the frequency bands 275-286 GHz, 318-334 GHz, 350-356 GHz, 361-365 GHz, 369-392 GHz, 397-399 GHz, 409-411 GHz, 416-434 GHz, 439-450 GHz sharing may be possible.

A4.3.3 Summary

According to Study 2 results the frequency bands 275-286 GHz, 318-334 GHz, 350-356 GHz, 361-365 GHz, 369-392 GHz, 397-399 GHz, 409-411 GHz, 416-434 GHz, 439-450 GHz were determined as the bands where the sharing between EESS (passive) and FS is possible.

The 286-296, 356-361 GHz, 365-369 GHz, 392-397 GHz, 399-409 GHz, 411-416 GHz and 434-439 GHz bands are not identified for use by EESS(passive) and therefore can be used for land mobile and fixed service applications without conditions.

A4.4 Study 3: Compatibility analyses between EESS (passive) and FS/LMS in the 275-450 GHz frequency range

The analyses in this section examine the interference potential that may result from FS and LMS applications operating in the 275-450 GHz frequency range to the EESS (passive) systems that would also operate in that frequency range.

A4.4.1 Analysis methodology

The approach taken in these analyses was to:

1 Select the worst case FS and LMS application characteristics.

2 Set an interference apportionment amongst the described FS and LMS applications.

3 Perform a single FOV analysis of each type of passive sensor identified to be considered for each of the EESS (passive) frequency bands identified in RR. No. **5.565**. The analysis is to determine the necessary FS and LMS application device deployment density that would be necessary to exceed the Recommendation ITU-R RS.2017 interference threshold protection level.

4 Examine the resulting deployment densities for their ability to be realized.

5 Refine the studies as necessary based on the results.

Limb Sounders

Limb sounders do not point at the earth, rather, they point tangentially through the atmosphere. Thus the worst case geometry for interference for Limb sounder is when interferers are at the nadir of the sensor. The analysis deployed FS and LMS emitters at the nadir of the sensor and iteratively increased the density uniformly to explore the sensitivity to device density.

Conical and nadir scanning sensors

The methodology used for conical and nadir scan sensors is similar to that used for the analyses concerning the Limb sounders. The conical scan sensor has a fixed off nadir angle and therefore a fixed slant path from an IFOV toward to sensor. For the conical scan sensors the FS/LMS interferers were deployed in this IFOV. The nadir scan sensor has a variable of nadir angle, but the worst case geometry is when the beam is at the nadir of the sensor, therefore interferers were deployed in the nadir IFOV of the sensor. The interference seen by the conical or raster scanning sensor can be dominated by a single FS emitter when main beam to main beam alignment between sensor and the FS emitter occurs. This type of interference occurrence is described in § A4-2 in regards to conical scanning sensors but this type of interference occurrence is also applicable to raster scanning sensors. Therefore, the analyses examine at what level of FS emitter deployment density the data availability prescribed by Recommendation ITU-R RS.2017 is exceeded.

The antenna elevation pointing of the FS antenna is assumed to vary uniformly over the defined antenna elevation range. The incident beam angle for the conically scanning sensor in a particular band is provided in Table A4-3. The incident beam angle of the raster scanning sensor can vary between about 18 and 60 degrees. Since the antenna elevation angle for an FS application is assumed to vary uniformly between 0 and 67 degrees in the worst case, the probability of main-beam-to-main-beam alignment between the FS antenna and the raster scanning sensor antenna is the same for any incident angle of the raster scanning antenna; therefore, for the purposes of analyses in this section a 60 degree incident angle is chosen for the raster scanning sensor. However, regulatory policies could be used by administration to limit the elevation angels of FS sources in bands where high elevation angles are not compatible with EESS (passive) use.

Monte Carlo simulations of the deployment within a single sensor footprint area are performed with increasing deployment densities until the point where the resultant indicate that the data availability criteria of Recommendation ITU-R RS.2017 has been exceeded. This deployment density where exceedance of the data availability criteria occurs will be then examined in terms of it being an achievable emitter density. If it is considered to be an achievable emitter density, then further refinement of the FS application deployment may be considered.

In examining the interference impact from LMS applications to the conical and raster scanning sensors, the LMS emitter deployment density within a single sensor footprint is increased until the point where the interference threshold level criteria prescribed by Recommendation ITU-R RS.2017 is exceeded. This deployment density where exceedance of the interference threshold level criteria occurs will be then examined in terms of it being an achievable emitter density. If it is considered to be an achievable emitter density, then further refinement of the LMS application deployment may be considered. It is not considered necessary to perform Monte Carlo simulations of the LMS deployment as the beamwidth of the LMS antenna is broad.

A4.4.2 Characteristics of the EESS (passive) systems

The EESS (passive) sensors to be used for sharing studies in the frequency bands identified for usage by EESS (passive) in RR No. **5.565** are listed in Table 12 of the main body of this Report. The characteristics of those sensors in Table 12 are provided in Table 13 of the main body of this Report. A summary of the EESS (passive) sensor characteristics to be used in the analyses is provided in Table A4-4 below.

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, is used to derive the EESS (passive) sensor antenna parameters in the 275-450 GHz frequency range where those parameters are needed to perform the required analysis.

TABLE A4-4

EESS (passive) characteristics for the frequency bands identified in RR. No. 5.565

	Frequency band (GHz)																	
	275-286	**296-306**		**313-356**			**361-365**		**369-392**		**397-399**		**409-411**	**416-434**		**439-467**		
Parameters	Limb[2]	Limb[3]	Conical[4]	Limb[5]	Nadir[6]	Conical[7]	Limb[8]	Conical[9,10]	Limb[11]	Raster[12,13]	Limb[14]	Conical[15,16]	Limb[17]	Limb[18]	Raster[19,20]	Limb[21]	Nadir[6]	Conical[22]
Altitude (km)	817	817	817	817	817	817	817	817	817	35 684	817	817	817	817	35 684	817	–	817
Nadir angle	–	–	45º	–	0º	45º	–	45º	–	–	–	45º	–	–	–	–	0º	45º
Incident beam angle	–	–	–	–	–	–	–	–	–	~18º–60º	–	–	–		~18º–60º	–	–	–
Minimum pointing altitude (km)	6	3	–	3	–	–	6	–	6	–	6	–	6	6	–	6	–	–
Centre Frequency (GHz)	280.5	299.75	301	320.0	–	325.15	363.0	363.0	370.5	380.197	398.0	398.0	410.0	425.0	424.76	453.0	–	448.0
Bandwidth	11.0	11.5	5	9.0	3	3	4.0	4.0	3.0	4.0	2.0	3.0	2.0	12.0	1.0	12.0	3	3
Ant. Peak Gain	70	80[23]	55	80[23]	55	55	70	55	70	(3m dia.)	70	55	70	70	(3m dia.)	70	55	55
FOV (km)	h = 5 v = 2.5	2.3 × 4.6	~200 km^2	2.3 × 4.6	~30 km^2	~200 km^2	h = 5 v = 2.5	~200 km^2	h = 5 v = 2.5	12 km^2	h = 5 v = 2.5	~200 km^2	h = 5 v = 2.5	h = 5 v = 2.5	10 km^2	h = 5 v = 2.5	~30 km^2	~200 km^2

2. Derived from STEAMR characteristics
3. MASTER
4. Derived from ICI characteristics
5. MASTER
6. Derived from Study 5 in this report
7. ICI
8. Derived from STEAMR characteristics
9. Listed as Nadir in Table 12, however a conical scanner is referenced.
10. Derived from ICI
11. Derived from STEAMR characteristics
12. Listed as Nadir, however a GEO raster scanner is referenced
13. Derived from GOMAS characteristics
14. Derived from STEAMR characteristics
15. Listed as Nadir in Table 12, however a conical scanner is referenced.
16. Derived from ICI
17. Derived from STEAMR characteristics
18. Derived from STEAMR characteristics
19. Listed as Nadir, however a GEO raster scanner is referenced
20. Derived from GOMAS characteristics
21. Derived from STEAMR characteristics
22 ICI
24. Extrapolated based on the antenna gain and FOV of STEAMR

A4.4.2.1 EESS (passive) interference protection criteria

Table A4-5 provides the interference level and data availability thresholds to be used in evaluating the compatibility of the proposed FS and LMS applications with EESS (passive) in the 275-450 GHz frequency range. For the raster scanning EESS (passive) sensors the thresholds of the nadir and conical scanning sensors are used as the operation of the raster scanning sensor and the resulting data products are comparable to that of those sensors.

TABLE A4-5

Extract of Recommendation ITU-R RS.2017 showing the interference criteria for satellite passive remote sensing in the frequency range 275-450 GHz

Frequency band(s) (GHz)	Reference bandwidth (MHz)	Maximum interference level (dBW)	Percentage of area or time permissible interference level may be exceeded[(1)] (%)	Scan mode (*N, C, L*)[(2)]
275-285.4	3	−194	1	*L*
296-306	200/3[(3)]	−160/−194[(3)]	0.01/1[(3)]	*N*, *L*
313.5-355.6	200/3[(3)]	−158/−194[(3)]	0.01/1[(3)]	*N*, *C*, *L*
361.2-365	200/3[(3)]	−158/−194[(3)]	0.01/1[(3)]	*N*, *L*
369.2-391.2	200/3[(3)]	−158/−194[(3)]	0.01/1[(3)]	*N*, *L*
397.2-399.2	200/3[(3)]	−158/−194[(3)]	0.01/1[(3)]	*N*, *L*
409-411	3	−194	1	*L*
416-433.46	200/3[(3)]	−157/−194[(3)]	0.01/1[(3)]	*N*, *L*
439.1-466.3	200/3[(3)]	−157/−194[(3)]	0.01/1[(3)]	*N*, *C*, *L*

(1) For a 0.01% level, the measurement area is a square on the Earth of 2 000 000 km^2, unless otherwise justified; for a 0.1% level, the measurement area is a square on the Earth of 10 000 000 km^2 unless otherwise justified; for a 1% level, the measurement time is 24 h, unless otherwise justified.

(2) *N*: Nadir. *L*: Limb, *C*: Conical.

(3) First number for nadir or conical scanning modes and second number for microwave limb sounding applications.

A4.4.2.2 Measurement area

The measurement area to be used for evaluating interference to sensors operating in the 275-450 GHz needs to be evaluated to reflect the size of the instantaneous field of view (IFOV) of the EESS sensor. This evaluation is in keeping with the “unless otherwise justified” phrase in Recommendation ITU-R RS.2017, Table 1, footnote 1.

A4.4.3 FS and LMS application characteristics

Table A4-6 provides a summary of FS and LMS application characteristics used in the analyses of this section. For all analyses performed in this section it is assumed that there is a 100% overlap in the use of frequency with that of the EESS (sensor) used in the specific analysis.

TABLE A4-6

Summary of FS and LMS application characteristics (275-450 GHz)

	Enhanced CPMS (Fixed device)	**Intra-device**	**Data Centre**	**Point-to-point (Fronthaul/backhaul)**	
Maximum Tx e.i.r.p. (dBm/GHz)	40	36.7	40	275-325 GHz	380-445 GHz
				67	57
Antenna beamwidth (degree)	90	180	Less than 25	–	
Antenna elevation (degree)	90	0	45	0-65	
Antenna gain range (dBi)	30	Up to 20	Up to 30	24-50	
Antenna diameter	[TBD]*	[TBD]* (1)	[TBD]*	[TBD]*	
Antenna pattern	Gaussian	Gaussian	Gaussian	Rec. ITU-R F.699-7 (Single entry) Rec. ITU-R F.1245-2 (Aggregate)	
Building loss (where applicable)	–	–	[TBD]*	–	
Bandwidth overlap with EESS (sensor) (%)	100	100	100	100 (2)	

(1) Antenna diameter is based on a typical gain of 6 dBi.

(2) The Point-to-point (fronthaul/backhaul) application operates over the 275-325 GHz and 380-445 GHz frequency ranges. With these frequency ranges of operation this FS application will operate in a portion of the 313-365 GHz and the 369-392 GHz frequency ranges identified under RR. No. **5.565** as frequency bands where EESS (passive) will operate. However, the stated frequency range of these FS application operations will avoid 100% frequency overlap with the EESS (passive) sensors that have been identified as representative sensors operating I n those frequency ranges. For the purposes of the analyses in Section 3, the centre frequency of the EESS (passive) sensors operating in the 313-365 GHz 369-392 GHz frequency ranges will be modified to have a 100% frequency of operation overlap with this FS application where a 100% is not explicitly indicated. This is done so that the potential operation of EESS (passive) sensors at a different centre frequency within those two frequency ranges can be taken into account in the results of studies.

A4.4.3.1 Enhanced Close Proximity Mobile System (fixed device)

The Close Proximity Mobile System (CPMS) application described in § 5.1.1 contains two sub-systems: the CPMS application and the Enhanced CPMS application. For the purposes of analyses contained in § 3, only the fixed device of the Enhanced CPMS application is considered because:

1 it is intended to operate over the entire 275-450 GHz frequency range;

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* Note by the Secretariat: The term [TBD] indicates that no values have been provided for these elements at the time of the development of Report ITU-R SM.2450-0, which was approved with the understanding that these values may be derived from other elements provided in the Table or may be provided in a future version of the Report, as appropriate".

2 it operates at the same power as the CPMS application;

3 the fixed device is assumed to operated simultaneously as the mobile device and the fixed device transmits at an e.i.r.p. 15 dB higher than the mobile device and so the interference contribution of the mobile device is considered to be negligible to the total interference resulting from this application.

A4.4.3.2 Intra-device communications

The Intra-device communications application is more fully described in § 5.1.2. Although the application is stated to be typically shielded there is no indication that the implementation of this application will be shielded or under what circumstances it may or may not be shielded. Furthermore, there is no current information on the degree of attenuation that might be expected from such shielding. Another point that must be considered is that based on the description of the application in § 5.1.2, 50% of these devices are expected to be deployed in an outside environment. For these reasons, it was considered necessary to evaluate the potential interference resulting from an outdoor deployment of these devices with the assumption that no shielding has been implemented in the manufacture of the Intra-device application product. The antenna beamwidth for the Intra-device application was given as 180°. No antenna pointing information has been provided in the Intra-device application description in § 5.1.2; therefore, for the purposes of the analyses in § A4.3, the Intra-device application antenna elevation angle is assumed to be 0°.

A4.4.3.3 Wireless links in data centres

The Wireless links in data centres application is described in § 5.1.3. It is noted that this is an indoor-only application so that the use of building loss attenuation is needed in order to perform analysis of the potential interference that may result from the deployment of this application. This information is not available in Recommendation ITU-R P.2109 for this frequency range. However advice from ITU-R propagation experts suggested that the information could be extrapolated from the values of the Recommendation ITU-R P.2109.

A4.4.3.4 Point-to-Point fronthaul/backhaul

The point-to-point fronthaul/backhaul application is described in § 5.2.1. Section 5.2.1 indicates that the antenna elevation angle is a maximum of 20° based on the terrain elevation variations in Tokyo, Japan. In order to assess the impact of the global deployment of this application a maximum antenna elevation angle of 65° is considered. It is worth noting that Report ITU-R F.2239 dealing with FS in the 76-86 and 92-95 GHz, considered FS elevation angles up to 65°.

A4.4.4 Simulation results

The following section provides the interference analysis results between the EESS system and the various types FS and LMS applications that have been proposed under WRC-19 agenda item 1.15.

A4.4.4.1 Interference analysis of Enhanced CPMS (fixed device)

For this analysis, the measurement area of the EESS satellite was defined as the IFOV of the particular sensor being simulated. Inside the IFOV of the EESS sensor CPMS devices were deployed randomly and the density of the CPMS devices was increased parametrically starting at the deployment density specified in Table 1. It is important to note that this analysis does not provide the percentage of time that the protection criteria is exceeded.

The Enhanced CPMS and EESS characteristics used in this study are given in Tables A4-4 and A4-6 above. In this analysis the azimuth angle of the Enhanced CPMS devices was uniformly distributed between 0-360°. However, it is noted that the antenna beamwidth of the Enhanced CPMS is given as 90° and the elevation is given as +/–90°. For the purpose of this analysis the elevation angle of each Enhanced CPMS device is assumed to be matched with the incident angle of the sensor beam on earth as this will provide the worst case results, e.g. 90° for nadir scanning sensors and 37° for conical scanning sensors with an off nadir angle of 45°. This assumption will be re-examined in the event that the initial results do not indicate compatibility between the Enhanced CPMS application and the EESS (passive) sensor operations.

FIGURE A4-10

Interference received by conical scanning EESS sensor from CPMS devices

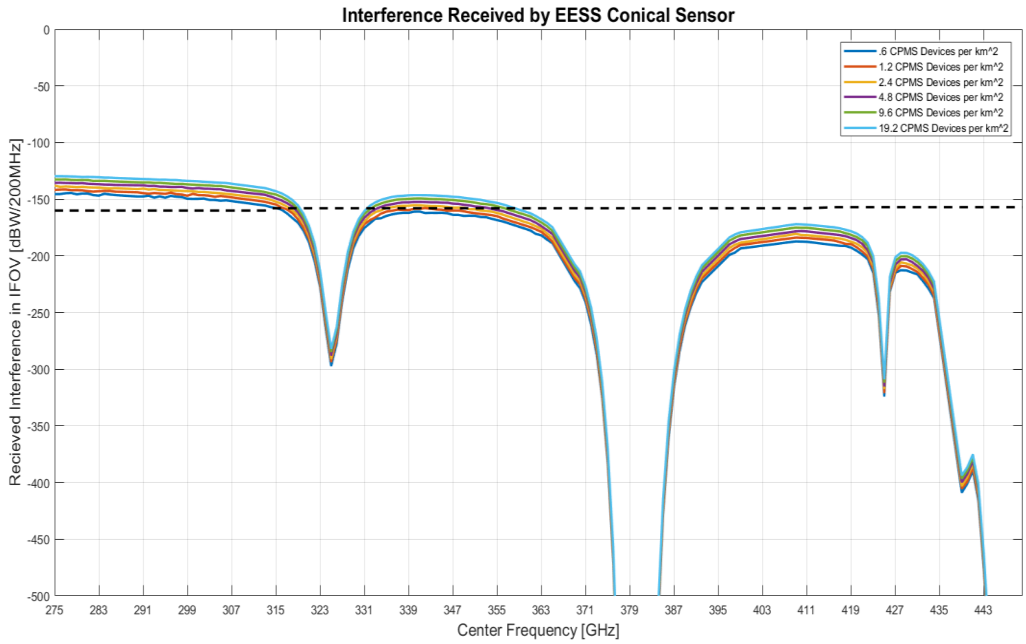


FIGURE A4-11

Interference received by Nadir scanning EESS sensor from CPMS devices

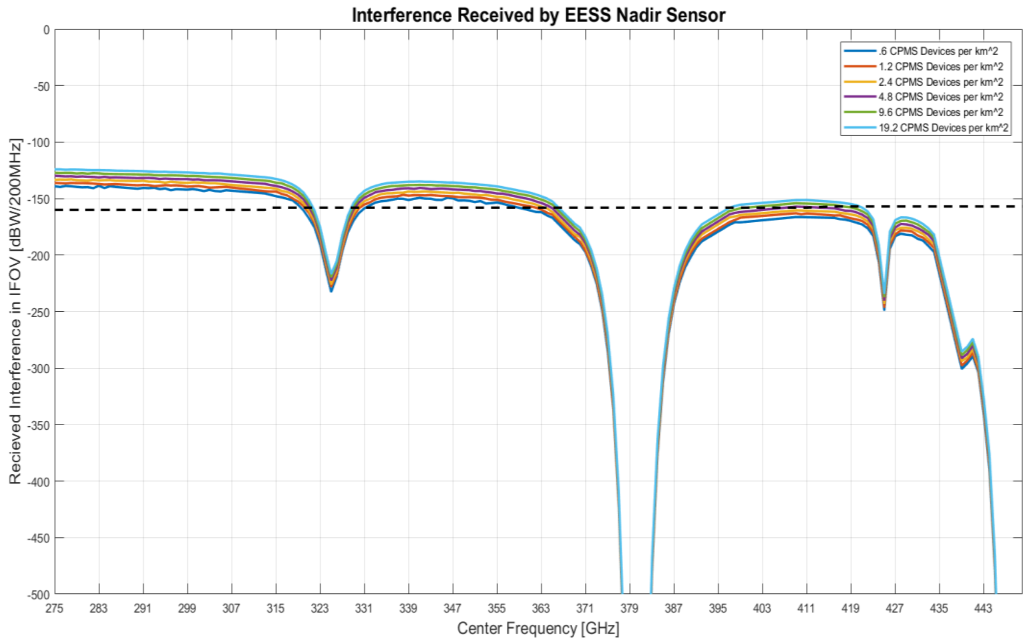
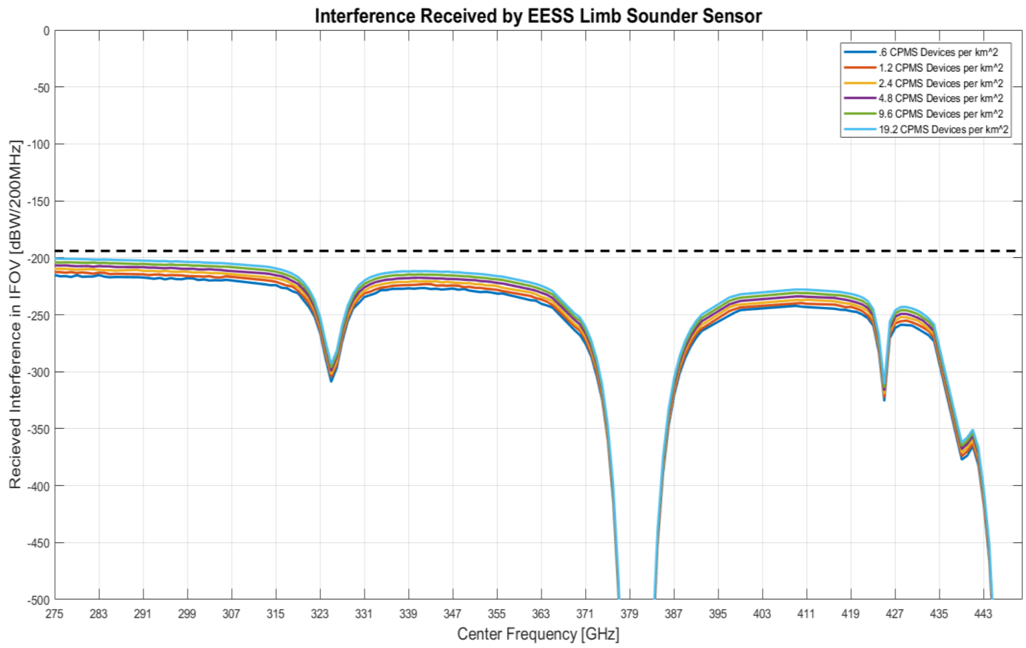


FIGURE A4-12

Interference received by limb sounder EESS sensor from CPMS devices



These results indicate that there may be incompatibility between CPMS devices and EESS (passive) over some bands identified for EESS (passive) usage. Given this, an additional analysis was done re-examining the pointing of the Enhanced CPMS devices. In the following analysis the azimuth of the Enhanced CPMS devices was randomly distributed over 0-360° and the elevations angles were randomly distributed over 0-90°.

FIGURE A4-13

Interference received by conical scanning EESS sensor from CPMS devices

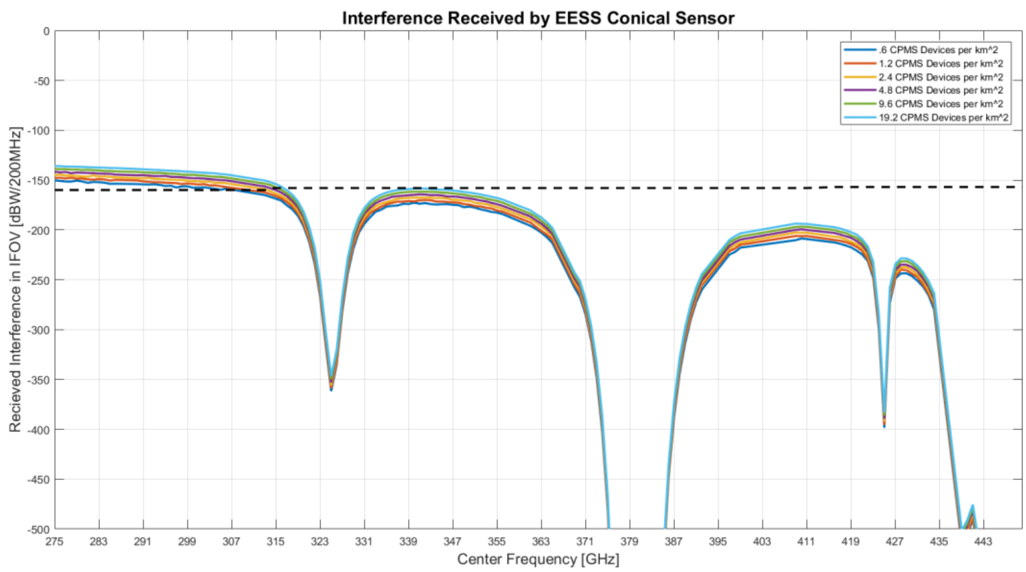


FIGURE A4-14

Interference received by Nadir scanning EESS sensor from CPMS devices

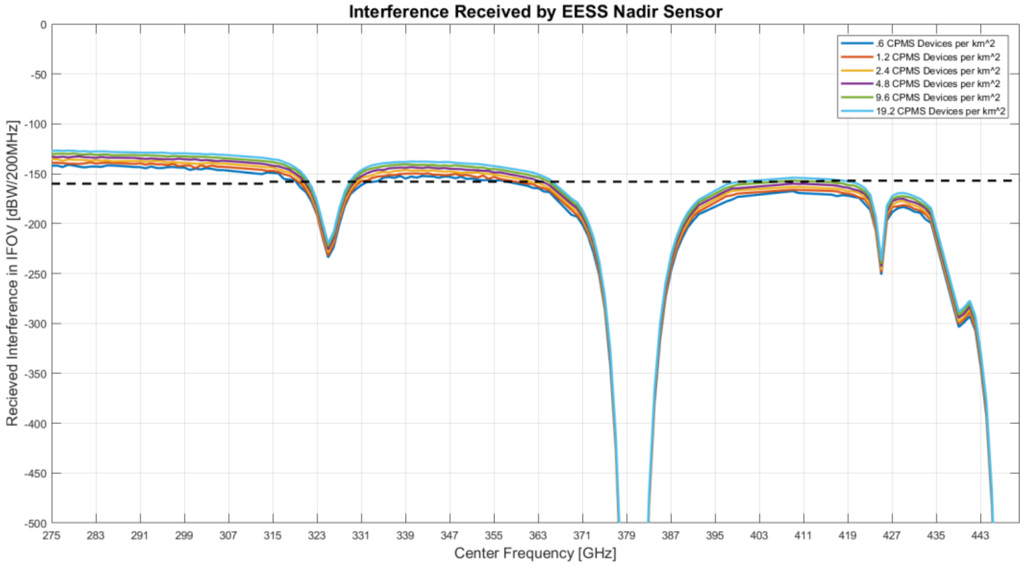
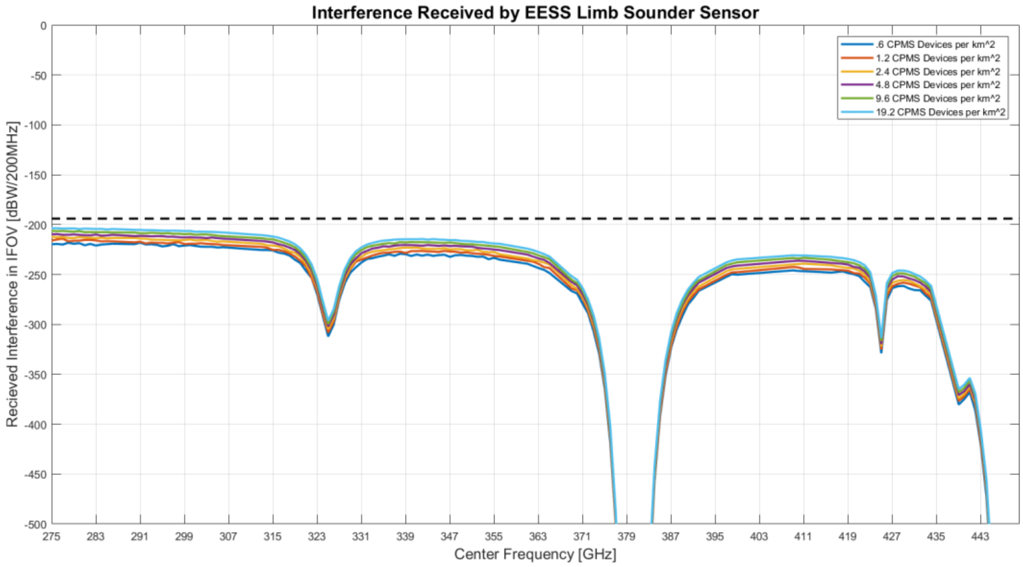


FIGURE A4-15

Interference received by limb sounder EESS sensor from CPMS devices



Based on the analysis above the following bands cannot be used by LMS applications without specific constraints:

– 296-306 GHz

– 313-320 GHz

– 330-356 GHz

A4.4.4.2 Interference analysis of Intra-device communications

For this analysis, the measurement area of the EESS satellite was defined as the instantaneous field of view (IFOV) of the particular sensor being simulated. Inside the IFOV of the EESS sensor Intra-device links were deployed randomly and the density of the Intra-device links were increased parametrically starting at the deployment density specified in Table 1.

The Intra-device links and EESS characteristics used in this study are given in Tables A4-6 and A4-4 above. It is noted that the antenna beamwidth of the Intra-device links is given as 180° and the elevation is given as 0°. For the purpose of this analysis the elevation angles of the Intra-device links are assumed to be fixed at 0° and azimuth angles were randomly distributed between 0-360°.

FIGURE A4-16

Interference received by conical scanning EESS sensor from intra-device links

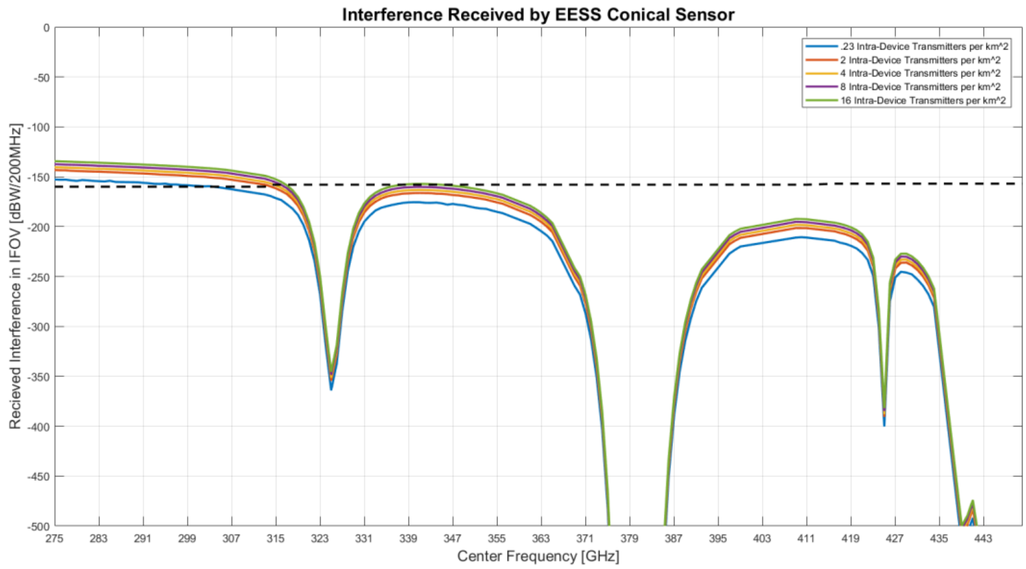


FIGURE A4-17

Interference received by Nadir scanning EESS sensor from intra-device links

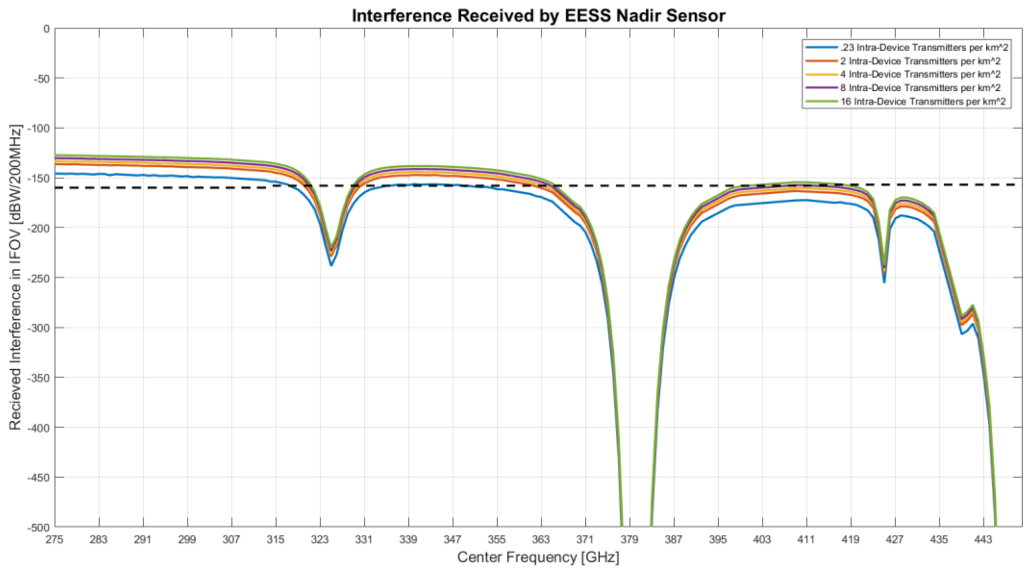
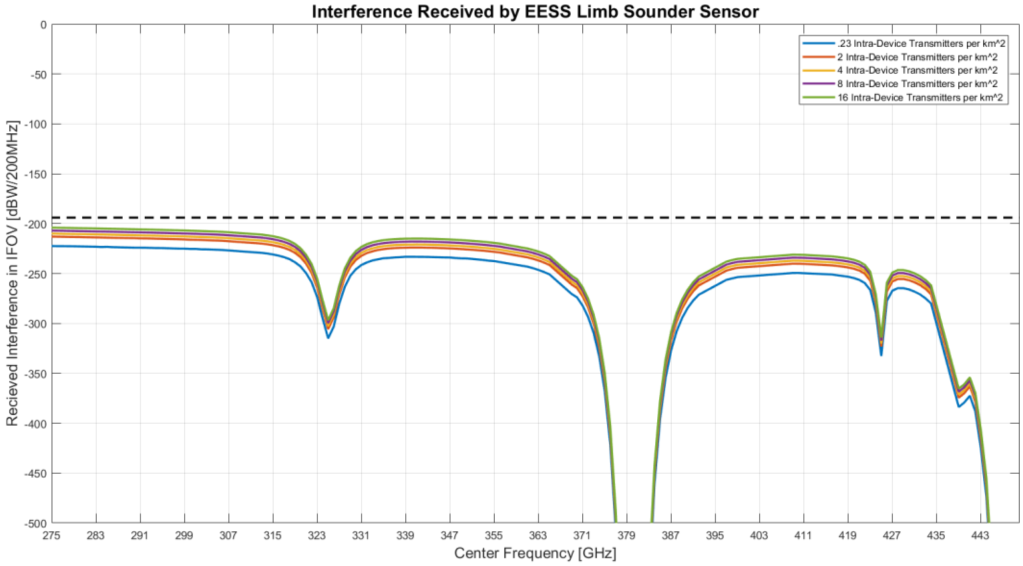


FIGURE A4-18

Interference received by limb sounder EESS sensor from intra-device links



Based on the analysis above the following bands cannot be used for LMS applications without more specific information as to the actual building entry loss and shielding values:

– 296-306 GHz

– 313-320 GHz

– 330-356 GHz

A4.4.4.3 Interference analysis of Wireless links in Data Centres

For this analysis, the measurement area of the EESS satellite was defined as the instantaneous field of view (IFOV) of the particular sensor being simulated. Inside the IFOV of the EESS sensor Data Centre links were deployed randomly and the density of the Data Centre links were increased parametrically starting at the deployment density specified in Table 1.

The Data Centre links and EESS characteristics used in this study are given in Tables A4-6 and A4-4 above. For the purpose of this analysis the elevation angles of the Data Centre links were assumed to be randomly distributed between 30-45° and azimuth angles were randomly distributed between 0-360°.

FIGURE A4-19

Interference received by conical scanning EESS sensor from data centre links

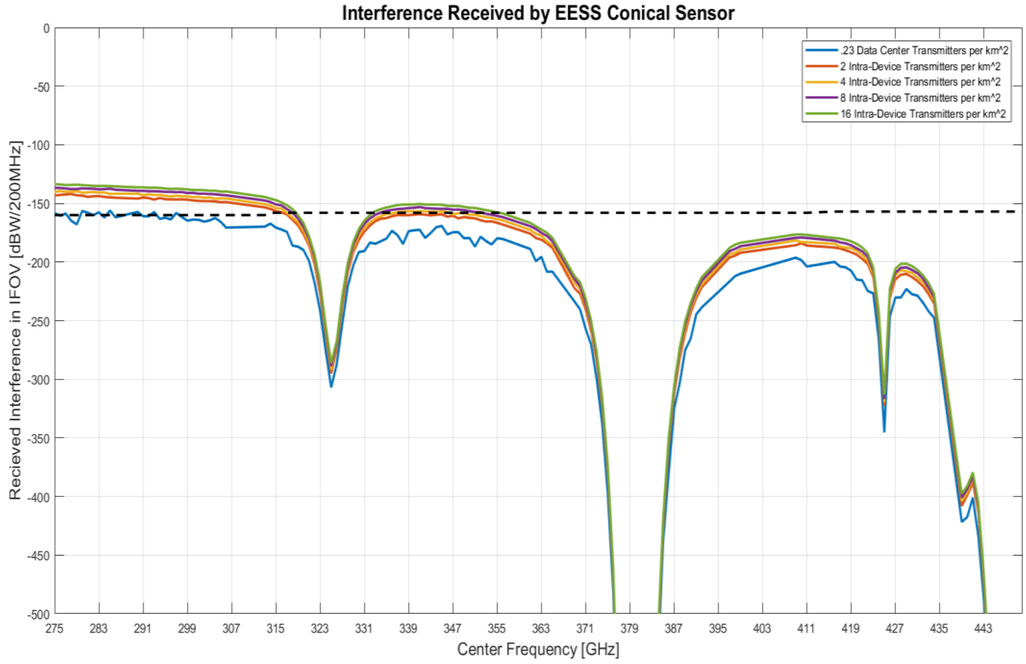


FIGURE A4-20

Interference received by Nadir scanning EESS sensor from data centre links

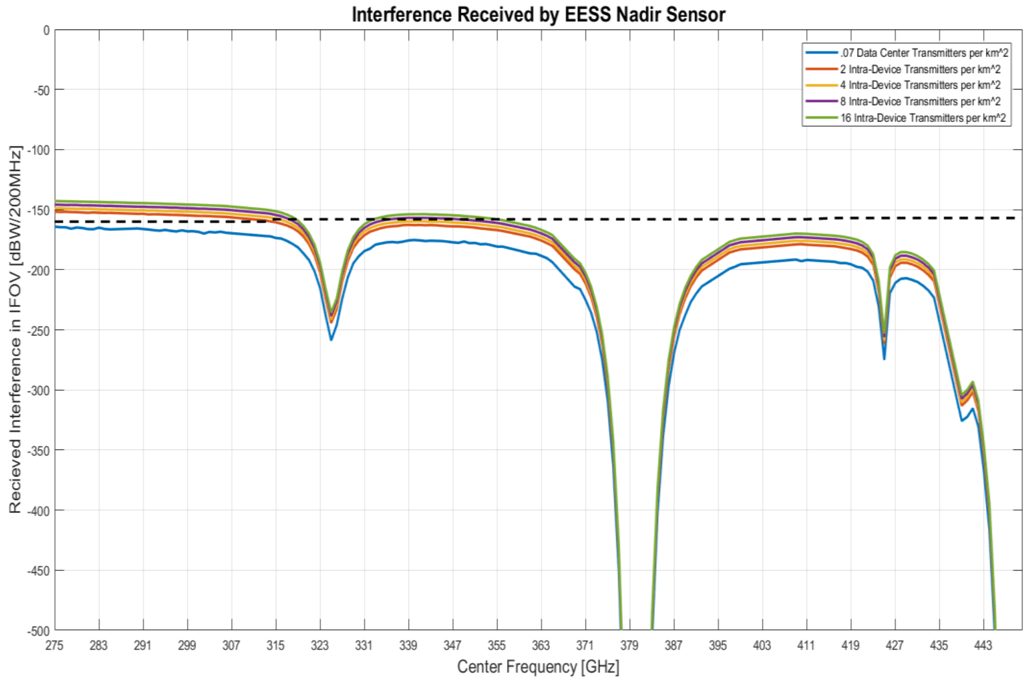
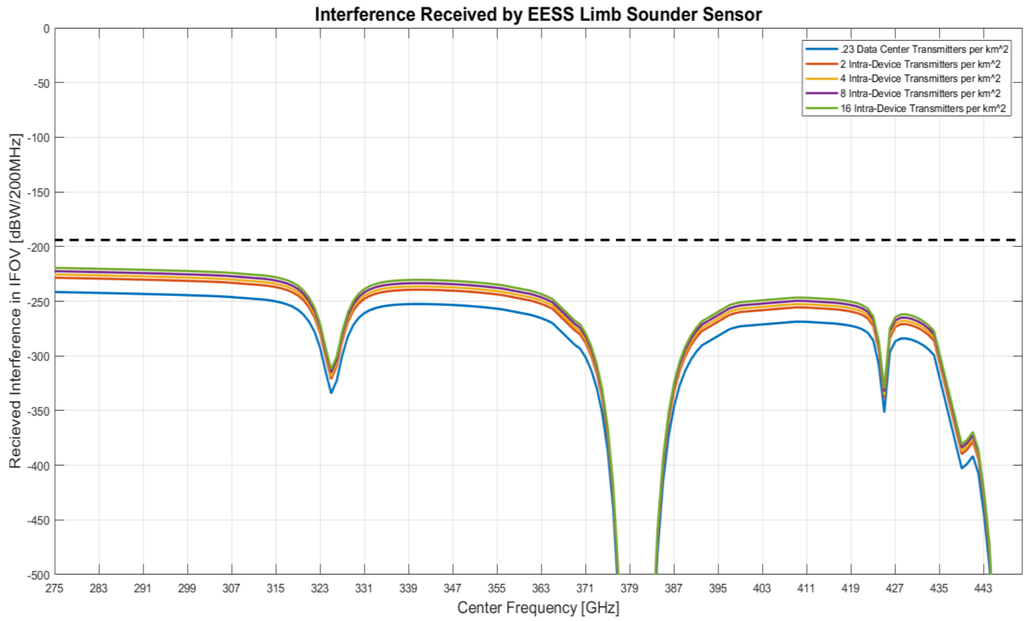


FIGURE A4-21

Interference received by limb sounder EESS sensor from data centre links



Based on the analysis above the following bands cannot be used for LMS applications without more specific information as to the actual building entry loss and shielding values:

– 296-306 GHz

– 313-320 GHz

– 330-356 GHz*

It should be noted that the upper band of 330-356 GHz, was incompatible without regulatory restrictions when densities of four links per km^2 were considered. Although the minimum deployment density given by the expert working group is .seven links/km^2, four links/km^2 is not viewed as an unachievable value.

A4.4.4.4 Interference analysis of Point-to-Point fronthaul/backhaul

For this analysis, the measurement area of the EESS satellite was defined as the instantaneous field of view (IFOV) of the particular sensor being simulated. Inside the IFOV of the EESS sensor FS links were deployed randomly and the density of the FS stations was increased parametrically starting at the deployment density specified in § 5.2.1 above. It is important to note that this analysis does not provide the percentage of time that the protection criteria is exceeded.

The FS and EESS characteristics used in this study are given in Tables A4-6 and A4-4 above. For the purpose of this analysis the elevation angles of the FS stations are assumed to be randomly distributed between –20 and +20° and azimuth angles were randomly distributed between 0-360°.

FIGURE A4-22

Interference received by conical scanning EESS sensor from FS links

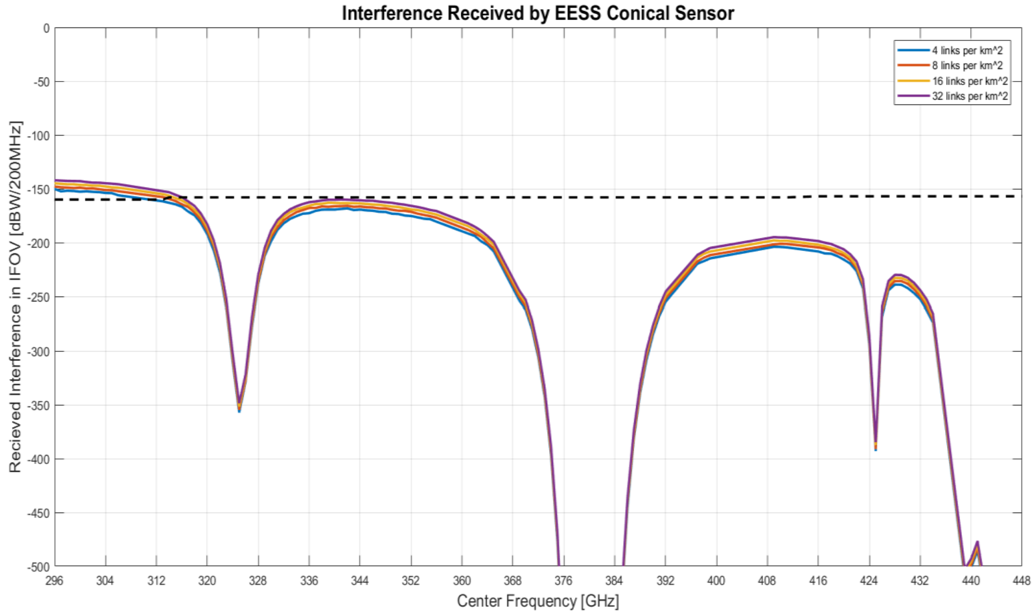


FIGURE A4-23

Interference received by Nadir scanning EESS sensor from FS links

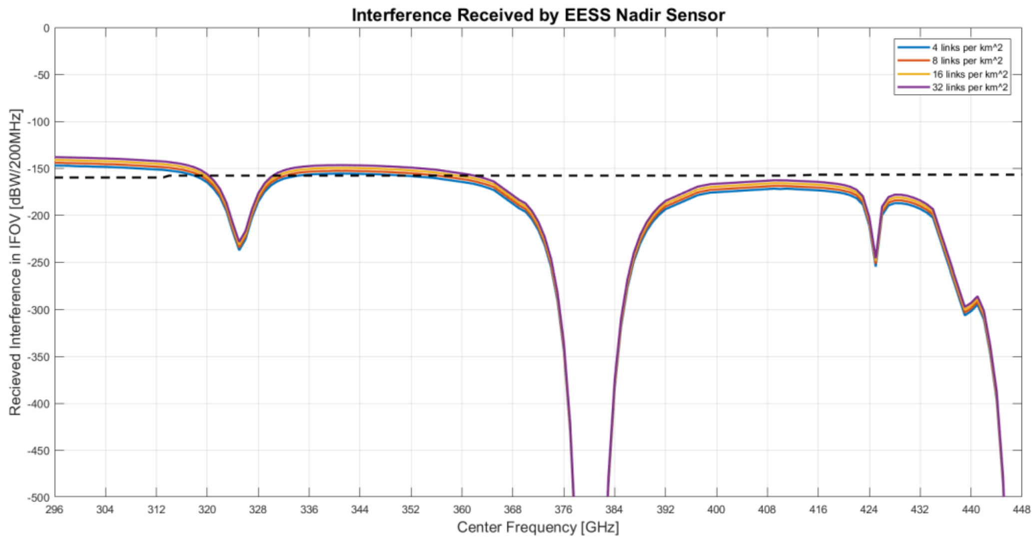
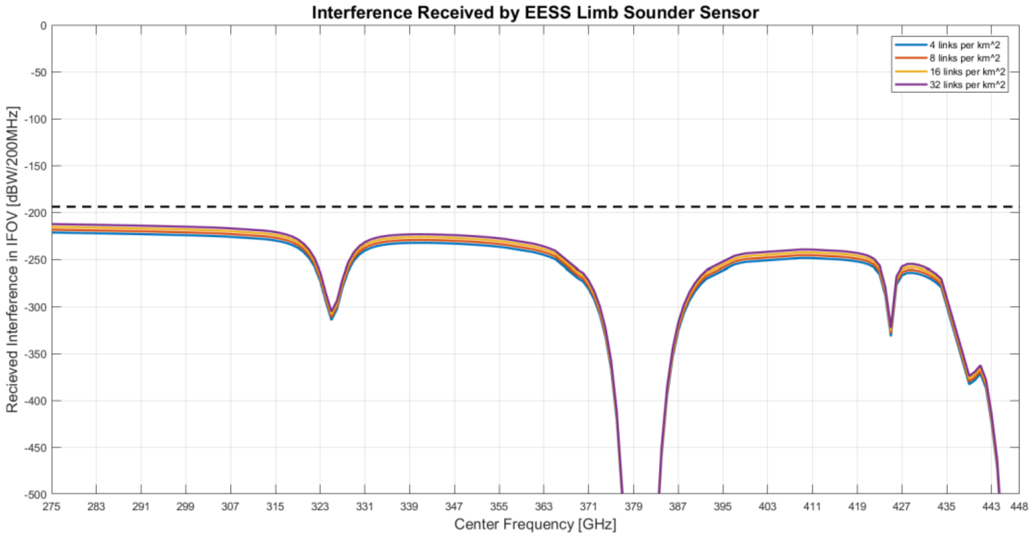


FIGURE A4-24

Interference received by limb sounder EESS sensor from FS links



The baseline distribution of elevation angles (maximum of 20°) used in the analysis above was provided by the expert working group. However, the maximum elevation of FS links in the range 275-450 GHz will not be regulated until such a time that actual allocations are made, therefore it is necessary to consider that a certain percentage of FS links could be operated at higher elevations. To that end, the analysis below was performed using the following distribution of elevation angles:

– 90% distributed between –20-25°

– 10% distributed between 25-65°

FIGURE A4-25

Interference received by conical scanning EESS sensor from FS links

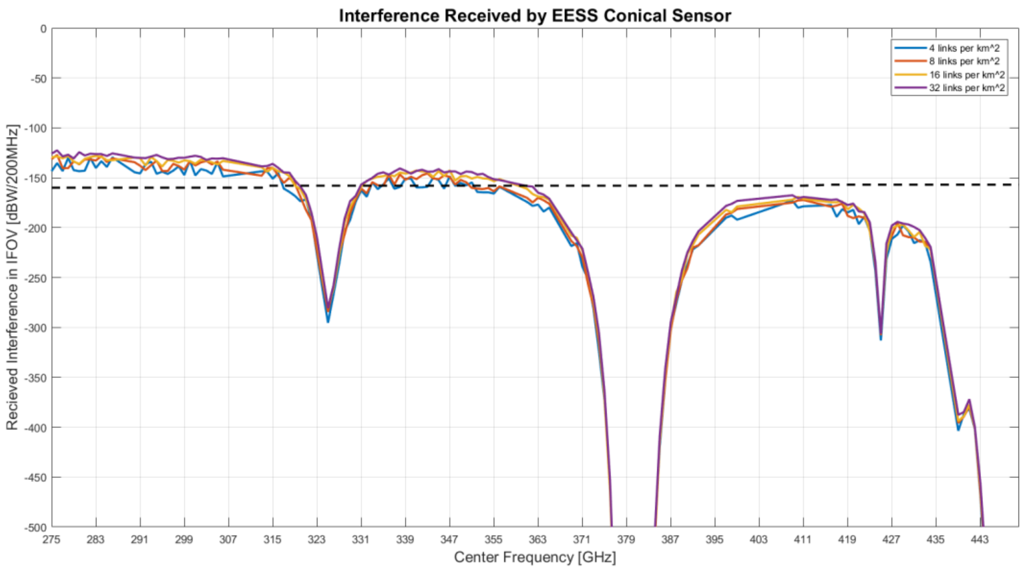


FIGURE A4-26

Interference received by Nadir scanning EESS sensor from FS links

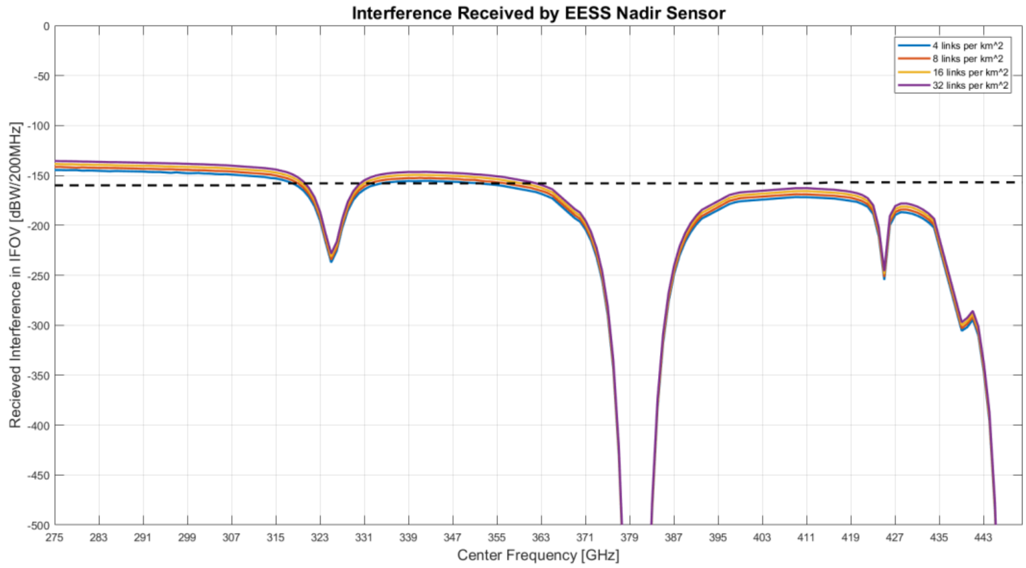
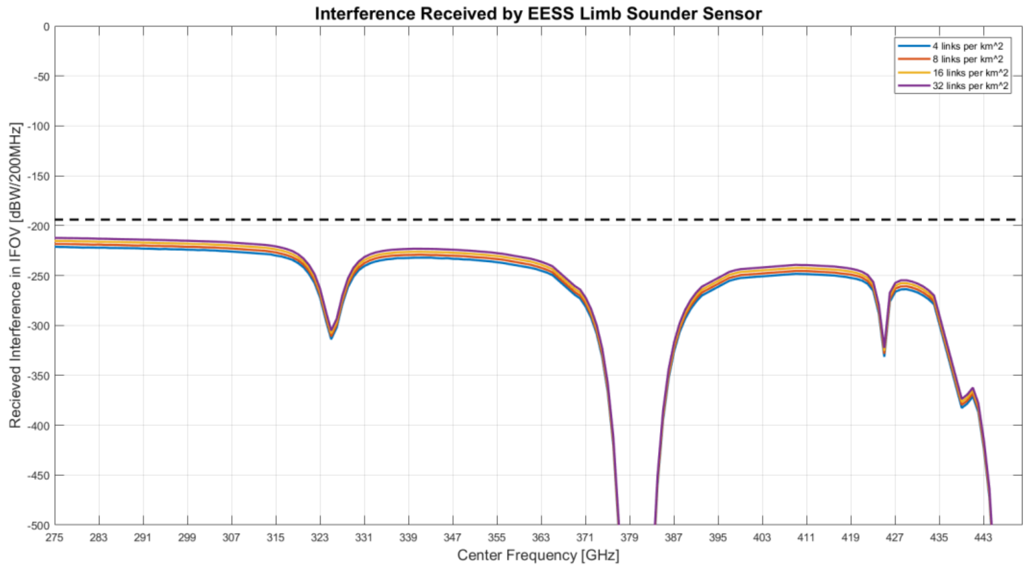


FIGURE A4-27

Interference received by limb sounder EESS sensor from FS links



Based on the analysis above the following bands cannot be used by FS applications without specific constraints:

– 296-306 GHz

– 313-320 GHz

– 330-356 GHz

A4.4.5 Summary of Study 3

Based on the analysis above the following bands can be used by FS/LMS applications without specific conditions:

– 275-296 GHz
– 306-313 GHz
– 320-330 GHz
– 356-450 GHz

It should be noted that in the band 275-286 GHz FS/LMS applications were found to be problematic for both conical and nadir scanning sensors, however this band currently only used by limb sounders. FS/LMS applications were determined to be compatible in this band due to this, however if other EESS(passive) sensors are deployed in this band in the future this conclusion should be re-evaluated; conical and nadir scanning sensors types will need to be taken into account if allocations are considered in this band.

These results are based on the specific parameters provided by the expert working group, however in the future if allocations are sought in the 275-450 GHz band further studies could be done to identify regulatory provisions (such as power limits and/or elevation angle restrictions) that would ensure compatible sharing between FS and EESS(passive).

A4.5 Study 4: Aggregate analysis of sharing between FS/LMS stations and EESS (passive) between 275-325 GHz

A4.5.1 Introduction

The frequency bands 275-286 GHz, 296-306 GHz and 313-356 GHz are identified for use for Earth exploration-satellite service (passive), and a lot of satellite passive remote sensing systems are operated as shown in Table 13 of the main body of this report. This section provides the sharing study results between FS/stations and EESS passive sensors, and between a specific application of the LMS, CPMS kiosk systems.

A4.5.2 Received power level of EESS passive sensor

The received power of EESS antenna is given by the following equation:

$$P_R = P_T + G_T + G_R - L_{BW} - PL - A$$

where:

P_R: power at the output port of the receive antenna

P_T: power at the input port of the transmit antenna

G_T: gain of the transmit antenna in the direction of the receive antenna

G_R: gain of the receive antenna in the direction of the transmit antenna

L_{BW}: bandwidth limiting factor

PL: "traditional" path loss between transmit and receive antennas due to geometric spreading and terrain blockage

A: additional loss factor due to atmospheric absorption.

The parameters in the frequency band 275-325 GHz in Tables 7 and 8 are used for calculation of the received power level of EESS (passive) whose characteristics are based on ICI in Table 14. The gain of the FS antenna at the zenith direction is assumed to be –13 dBi in accordance with Recommendation ITU-R F.1245. The path loss from a terrestrial point to EESS (passive) whose altitude is 817 km is referred from Fig. 6. Although three altitudes of 0 m and 1,000 m where LMS/FS antennas are placed are considered for sharing and compatibility analyses, the study results are summarized by use of the altitude less than 1,000 m because major large cities whose population is over 10 million in the world are located between 0 m and 1,000 m.

A4.5.3 CPMS deployment

This section provides the technical and operational characteristics of CPMS applications to be used for sharing studies between CPMS and EESS (passive) in accordance with Report ITU-R M.2417. CPMS applications are used in indoor environment and almost all antenna elevation angles of CPMS fixed devices for KIOSK and ticket gate downloading mobile systems are +90°. Those CPMS fixed devices start to operate when CPMS mobile devices are closely placed on those devices. CPMS mobile devices can also be expected to provide some shielding of the radiation power from the CPMS fixed devices to the surroundings because of close proximity contact. Even though two devices are faced very closely, the leakage power may be radiated from interspace between two devices. However, this unwanted leakage power is not taken into account in this study. Although the antenna elevation angle of CPMS mobile devices in operation is −90°, the worst-case scenario whose antenna elevation angle of +90 is taken into account for the studies. Table A4-7 summarizes the technical and operational parameters used for the sharing studies between this LMS application matching the operating and deployment characteristics of KIOSK downloading mobile systems with EESS (passive). The BEL of 28 dB for traditional buildings are used for the study in order not to overestimate the BEL value at the 300 GHz band.

TABLE A4-7

Summary of technical and operational parameters of CPMS applications to be used for sharing studies

Parameters	Values	Remark
Frequency range (GHz)	275-450	CPMS application in Report ITU-R M.2417
Antenna elevation (degree)	+90	Antenna gain of CPMS fixed device: 30 dBi (see Annex 3)
	+90	Antenna gain of CPMS mobile device:15 dBi (see Annex 3)
Indoor CPMS fixed device deployment (%)	90	The value of the enhanced CPMS application in Report ITU-R M.2417 is applied.
Building entry loss (dB)	28	Extrapolation value based on Rec. ITU-R P.2109 (see Annex 2)

A4.5.4 FS deployment

The elevation angles of the antenna are calculated from the antenna height of FS stations and the distance of FS links. Report ITU-R F.2417-0 specifies the elevation angle within ±20 degrees of FS stations in the urban areas where the height of FS station is in the range 6-25 m and the distance between FS stations in the range 100-300 m. However, the possibility of links as high as 30 degrees elevation should be considered as a worst case for the short distance dense-urban links at high elevation, as proposed in Report ITU-R F.2239-0.

Although FS link density of 4.2/km^2 is specified in the frequency range 275-325 GHz and 380-445 GHz in accordance with Report ITU-R F.2417-0, this FS link density is used for the sharing studies in the entire frequency band of 275-450 GHz.

A4.5.5 Received power level of EESS (passive) sensors

Table A4-8 summarizes the parameters which are used for calculation of aggregate received power of EESS (passive) sensors. All bands in the frequency range 275-450 GHz identified for use of EESS (passive) sensors are assessed in accordance with § 5.2.

TABLE A4-8

Parameters of EESS (passive) to be used for sharing studies

EESS (passive) sensors	**Received bandwidth of sensors (MHz)**	**Nadir angle (degree)**	**Aggregate effect**	
Limb	3	0	N/A Pointing of 30 dBi antenna of CPMS fixed device to EESS (passive) sensor (Worst-case scenario)	N/A Pointing to 50 dBi antenna of FS station to EESS (passive) sensor (Worst-case scenario)
Nadir [(1)]	200	90	Device density=0.6/km2 IFOV=30 km^2 (ICI), 10 km^2 (TWICE), 110 km^2 (GOMAS) Number of devices=18 (ICI), 6 (TWICE), 66 (GOMAS) Activity factor=0.76% Cumulative probability distribution < 0.01%	FS link density=4.2/km^2 IFOV=30 km^2 (ICI), 10 km^2 (TWICE), 110 km^2 (GOMAS) Number of transmitters=252 (ICI), 84 (TWICE), 924 (GOMAS) Distribution of FS stations: Discrete uniform distribution Average antenna gain = 5.2 dB (ICI), 0.8 dB (TWICE), 10.7 dB (GOMAS)
Conical	200	53	Device density=0.6/km^2 IFOV=200 km^2 (ICI) Pointing of 30 dBi and 15 dBi antennas of CPMS fixed and mobile devices to EESS (passive) sensor Elevation angle=25.7°	Pointing to 50 dBi antenna of FS station to EESS (passive) sensor Elevation angle=25.7°

[(1)] Received power to Nadir scanning mode sensor is calculated at 90 degree zenith direction only.

A4.5.5.1 Received power level from CPMS mobile systems

Figure A4-28 shows the study results which show the band 275-450 GHz is available for LMS applications if additional losses such as the BEL applies and can be taken into account. The following results are achieved from Fig. A4-28 (c):

a) The entire band 275-450 GHz cannot be used for CPMS applications in the condition of 10% outdoor use, since there would not be any building attenuation loss to be taken into account.

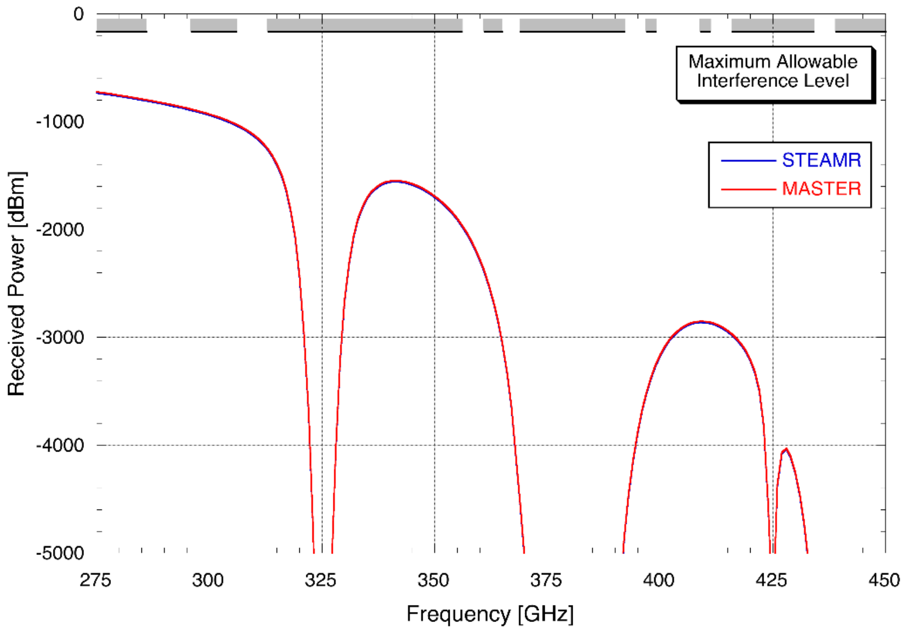
b) The bands 296-306 GHz, 313-316 GHz and 332-356 GHz cannot be used for CPMS applications if no additional losses are taken into account.

In summary, the bands 275-296 GHz, 306-313 GHz, 319-332 GHz and 356-450 GHz can be used for CPMS applications without any specific conditions. However, the entire band 275-450 GHz could be used for CPMS applications if the specific conditions such as the building loss is applicable for CPMS devices used indoors[7].

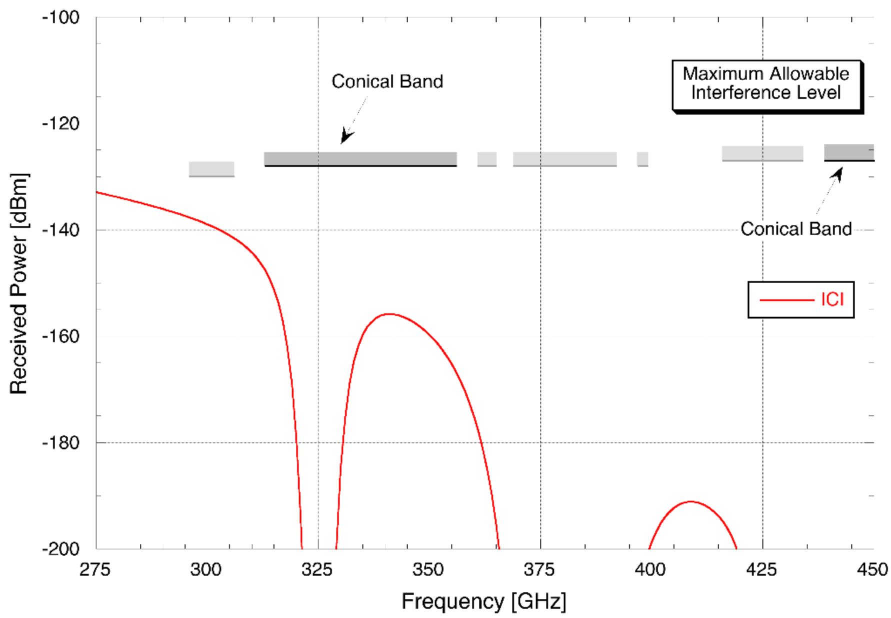
FIGURE A4-28

Received power level of EESS (passive) sensors from CPMS applications

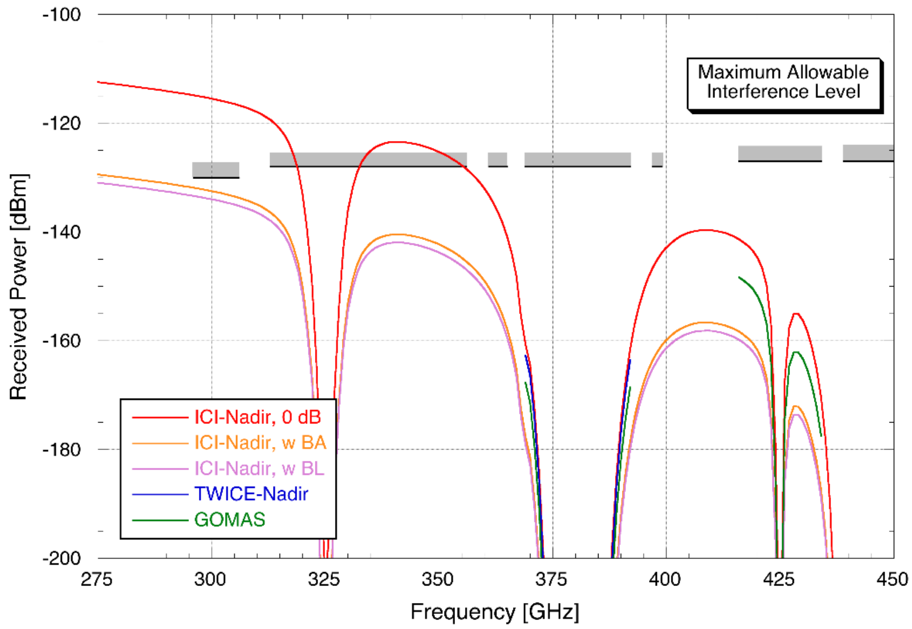
(a) Limb mode



(b) Conical scanning mode



(c) Nadir mode (If building attenuation of 17 dB is not taken into account for the sharing studies, the received power level exceeds the maximum interference level in the bands 296-306 GHz, 313-319 GHz and 332-356 GHz.)



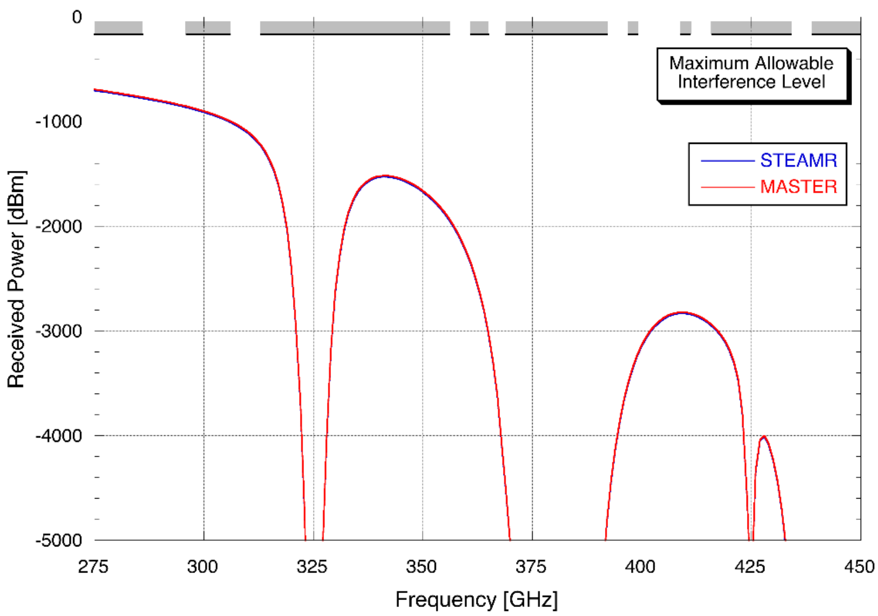
A4.5.5.2 Received power level from point-to-point fronthaul and backhaul

Figure A4-29 shows the calculated results of the received power level of EESS (passive) sensors. No interference from FS stations is observed for the limb and nadir mode sensors. However, the received power level exceeds the maximum interference level in the conical scanning bands 313-318 GHz and 336-348 GHz, and in the nadir band 296-306 GHz, as shown in Fig. A4-29 (b). In summary, the bands 275-296 GHz, 306-313 GHz, 318-336 GHz and 348-450 GHz can be used for FS applications without any specific conditions.

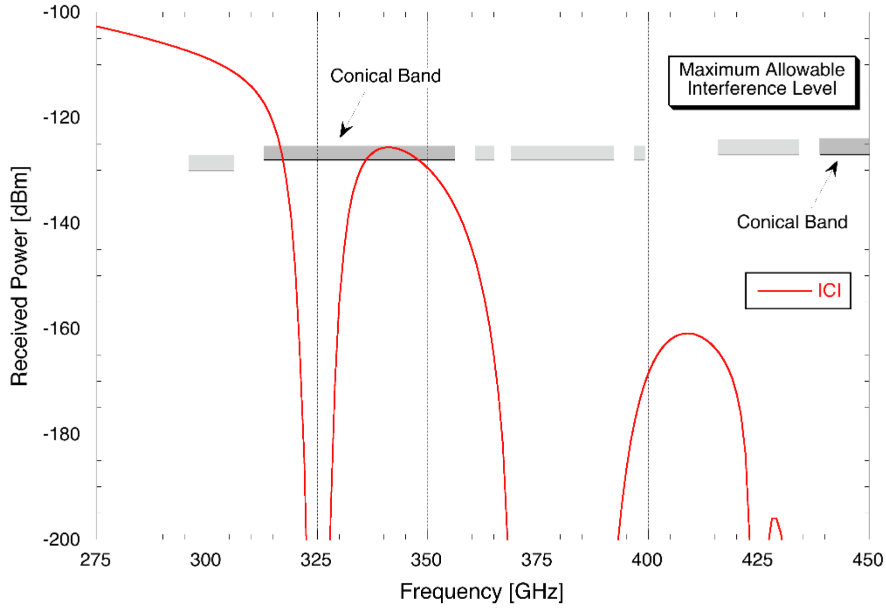
FIGURE A4-29

Received power level of EESS (passive) sensors from FS applications

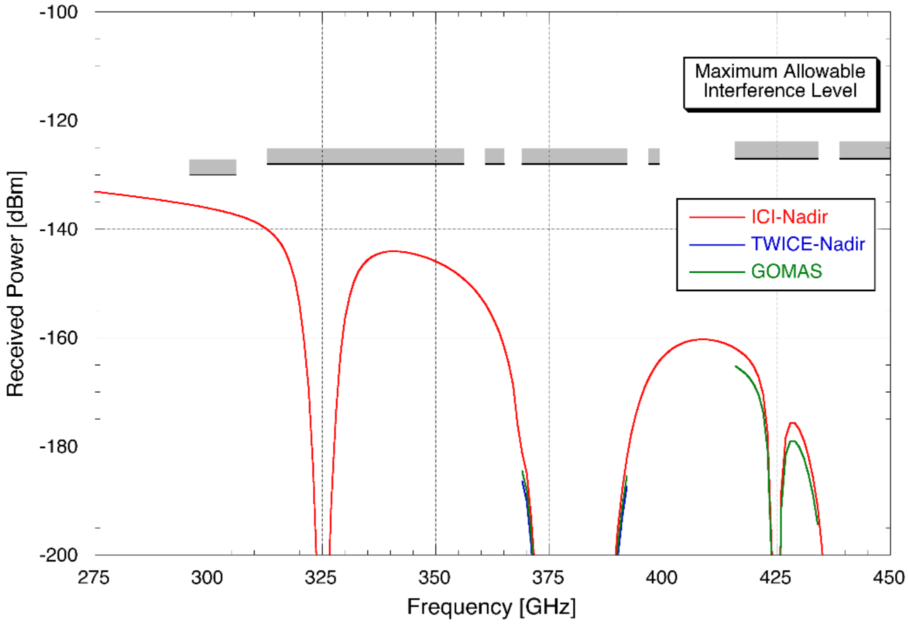
(a) Limb mode



(b) Conical scanning mode (The received power level exceeds the maximum interference level in the conical scanning bands 313-318 GHz and 336-348 GHz, and in the nadir band 296-306 GHz.)



(c) Nadir mode



A4.5.6 Summary of Study 4

The bands 275-296 GHz, 306-313 GHz, 319-332 GHz and 356-450 GHz can be used by CPMS applications without any specific conditions. The bands 275-296 GHz, 306-313 GHz, 318-336 GHz and 348-450 GHz can also be used by FS applications without any specific conditions. For compatibility of FS/LMS applications with EESS (passive), the bands 275-296 GHz, 306-313 GHz, 319-332 GHz and 356-450 GHz can be compatibly used by FS/LMS applications.

A4.6 Study 5: Compatibility analyses between EESS (passive) and FS in the 275-450 GHz frequency range (Aggregate case)

This study contains an aggregate interference analysis between FS systems and EESS (passive) in the band 275-450 GHz. The approach used in this analysis was to determine the maximum aggregate interference power generated by the FS stations deployed in the FOV of the EESS sensor and then calculate the minimum atmospheric attenuation that would be needed to ensure the EESS protection criteria would not be violated. This minimum atmospheric attenuation was then compared to the actual values predicted by Recommendation ITU-R P.676 to determine which bands were compatible.

A4.6.1 EESS (passive) characteristics

Description of EESS (passive) systems in the 275-450 GHz is given in § 5.4.

For the specific ICI system, the following parameters are necessary to undertake the sharing analysis:

TABLE A4-9

ICI characteristics

	ICI sensor
Orbit type	NGSO
Altitude (km)	817
Off-Nadir angle (degree)	53
elevation at ground (degree)	25.7
IFOV (km²)	200
Antenna gain (dBi)	55

The relevant ICI channels are:

– Channel 1: 314.15-317.15 GHz (3 GHz)

– Channel 2: 320.45-322.85 GHz (2.4 GHz)

– Channel 3: 323.65-324.45 GHz (1.6 GHz)

– Channel 4: 325.85-327.45 GHz (1.6 GHz)

– Channel 5: 327.45-329.85 GHz (2.4 GHz)

– Channel 6: 333.15-336.15 GHz (3 GHz)

In addition, in order to allow for a generic analysis in all frequency bands, five generic systems are considered, as described in Table A4-10.

TABLE A4-10

Generic EESS (passive) systems

	ICI Type	**TWICE Type**	**NADIR Type**	**GOMAS Type (Nadir)**	**GOMAS Type (Low elevation)**
Orbit type	NGSO	NGSO	NGSO	GSO	GSO
Altitude (km)	817	400	817	35 684	35 684
Off-Nadir angle (°)	53	53	0	0	8.5
elevation at ground (°)	25.7	31.9	90	90	12.7
IFOV (km²)	200	50	30	110	890
Antenna gain (dBi)	55	48	55	79	79

NOTE – Cross-track sensors can be represented by both the “the Nadir type” and the ICI “type”.

A4.6.2 FS characteristics and deployment

Description of FS systems in the 275-450 GHz is given in § 5.2.

The following technical parameters are necessary to undertake sharing analysis between FS and EESS (passive) systems.

– e.i.r.p. ranging 30 to 67 dBm/GHz
– Antenna gain ranging 24 to 50 dBi
– FS antenna pattern F.1245

With regards to the number of FS links, the following assumptions are considered:

– Link density scenario= 4.2 links/km²
– Population scenario = 0.00035 link/inhabitant

Finally, for the FS link elevation distributions, the baseline case provided by Report ITU-R F.2416 has been used, i.e. 20° typical (Case 1), which is not saying that higher elevations will not occur.

Under the assumption that the maximum elevation of FS links in the range 275-450 GHz will not be regulated, this study also considers the impact of a certain percentage of FS links operated at higher elevation. To this respect, the example of Report ITU-R F.2239 has been taken as a reference, depicting for the FS links in the 81-86 GHz the following elevation cases:

TABLE A4-11

FS elevation scenarios from Report ITU-R F.2239

	Case 2	**Case 3**	**Case 4**	**Case 5**
High elevation links	0.39% of links with elevation higher than 20°	0.5 % of links with elevation between 30° and 45°	± 30° (normally distributed)	Less than 2% of links with elevation between 20° and 65°

NOTE – It should be noted that since FS links hop lengths are more than likely being longer in the 81-86 GHz band than in the 275-450 GHz band, the FS elevation angles in the 275-450 GHz band may be higher.

In order to calculate the aggregate impact of an FS deployment on EESS (passive) sensors, the following methodology has been applied:

1st step: Determine the number of FS links in the EESS footprint:

– Option 1: density based (4.2 links / km²)
– Option 2: population based (0.00035 links / inhabitant) (see methodology in Annex 1)

TABLE A4-12

Number of FS links within the EESS (passive) footprint

	ICI Type	**TWICE Type**	**NADIR Type**	**GOMAS Type (Nadir)**	**GOMAS Type (low elevation)**
IFOV (km²)	200	50	30	110	890
Density based (number of links)	840	210	126	462	3 738
Population based (number of links)	1 030	393	228	874	1 903

2nd step: Random deployment of the number of FS links with the following parameters randomly chosen:

– Azimuth (0 to 360°)

– Elevation (based on above distributions cases 1 to 5)

– e.i.r.p. (30 to 67 dBm/GHz)

– Antenna gain (24 to 50 dBi)

3rd step: For each case, run 1 000 different random deployments to determine the distribution of maximum e.i.r.p. in the direction of the EESS (passive) sensor.

A4.6.3 Maximum FS e.i.r.p. in direction of the EESS (passive) satellite

The following sections present the maximum FS e.i.r.p. at the ground in direction of the EESS (passive) satellites (expressed in dBm/200 MHz).

a) Single entry

The maximum FS e.i.r.p. is given as 67 dBm/GHz. Therefore, expressed in dBm/200 MHz, the maximum single entry FS e.i.r.p. at the ground in direction of the EESS (passive) satellites is:

Max e.i.r.p. = 67 + 10 x log(200/1 000)= 60 dBm/200 MHz

b) Aggregate case for the ICI type sensor

FIGURE A4-30

FS e.i.r.p. at the ground for ICI type sensor (density based)

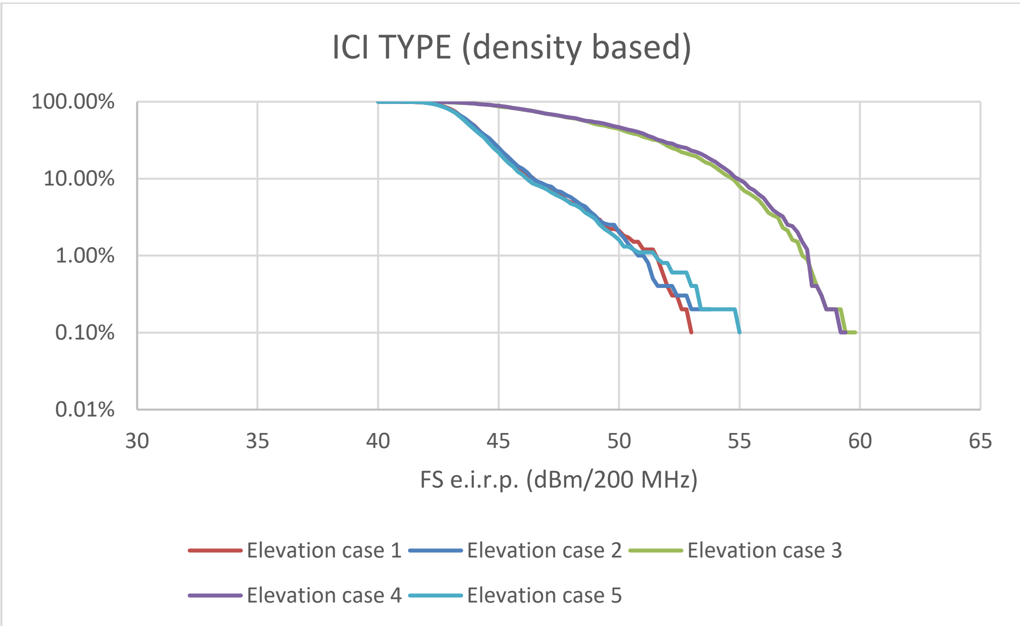
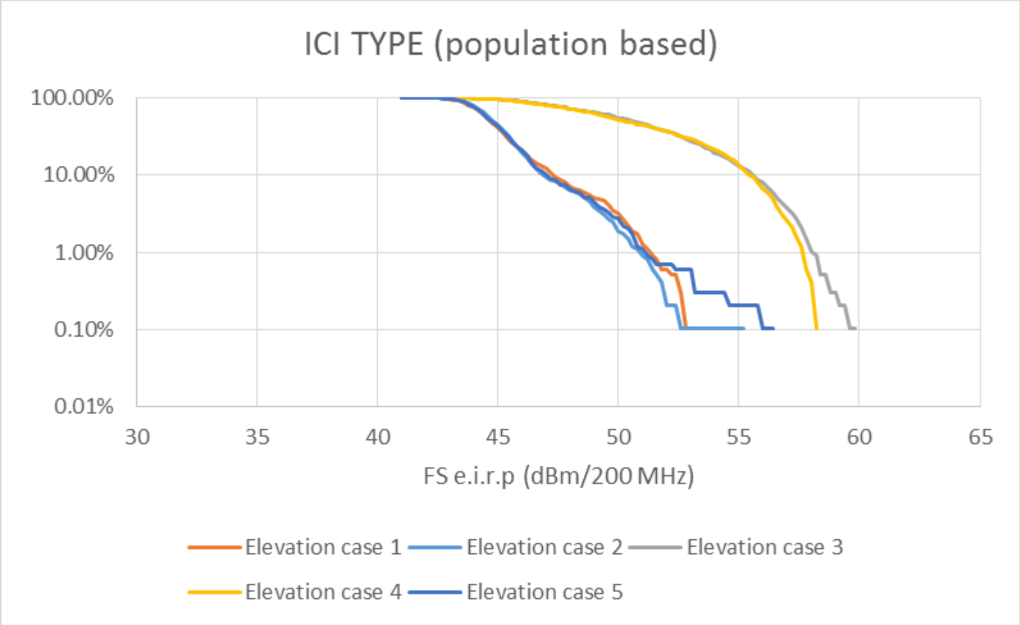


FIGURE A4-31

FS e.i.r.p. at the ground for ICI type sensor (population based)



Maximum aggregate e.i.r.p. from Figures above = 59.8 dBm/200 MHz.

c) Aggregate case for the TWICE type sensor

FIGURE A4-32

FS e.i.r.p. at the ground for TWICE type sensor (density based)

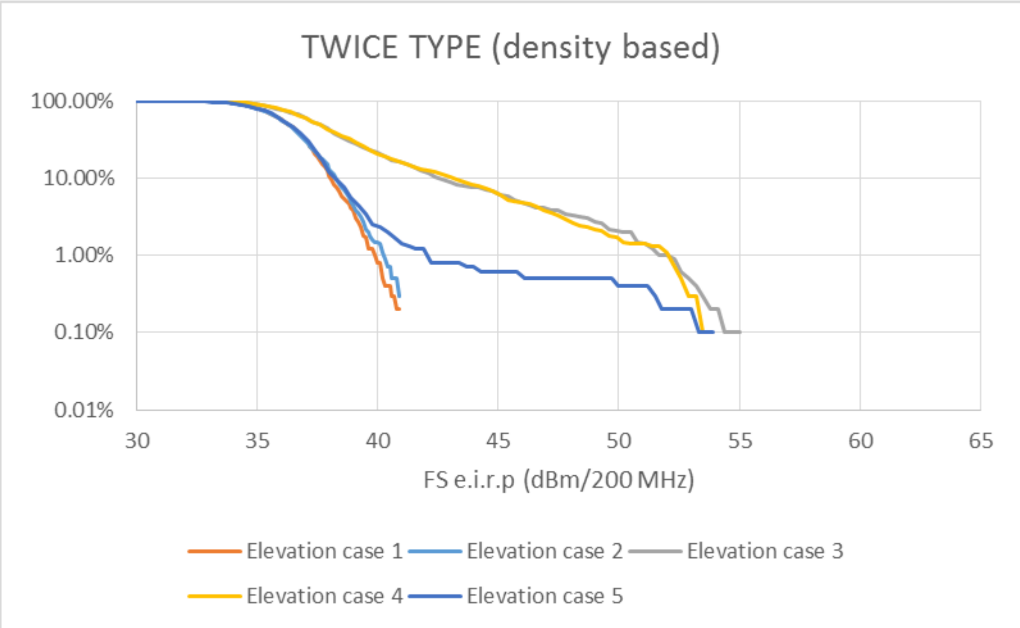
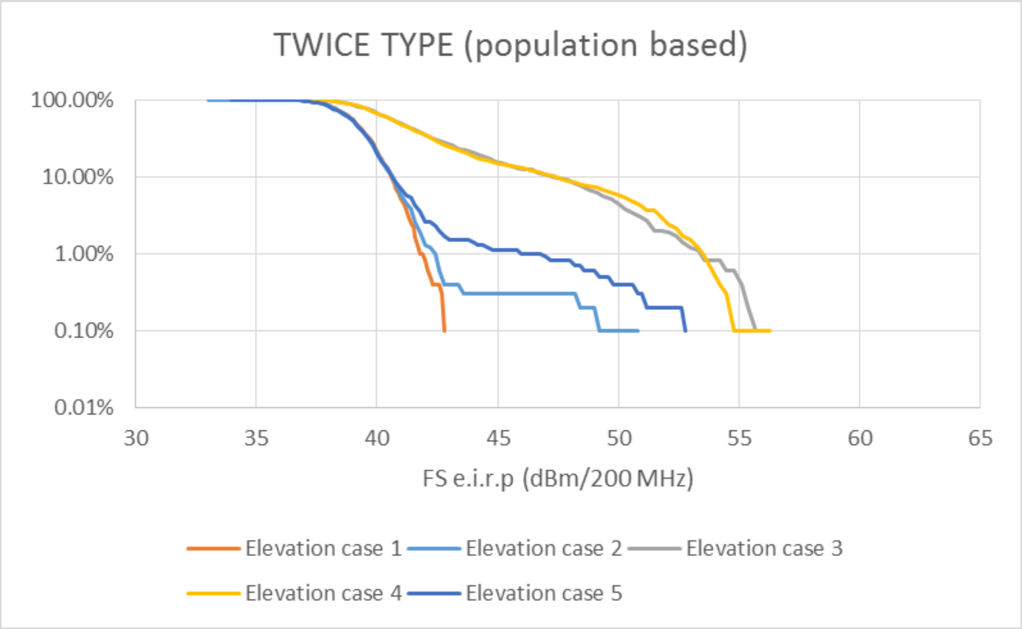


FIGURE A4-33

FS e.i.r.p. at the ground for TWICE type sensor (population based)



Maximum aggregate e.i.r.p. from Figures above = 56.3 dBm/200 MHz

d) Aggregate case for the NADIR type sensor

FIGURE A4-34

FS e.i.r.p. at the ground for NADIR type sensor (density based)

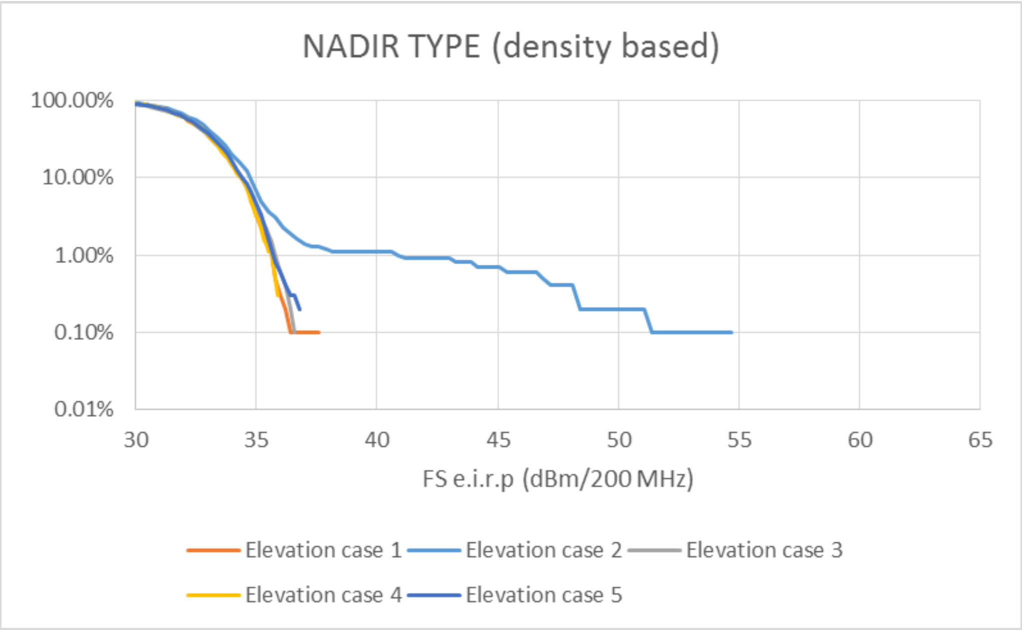
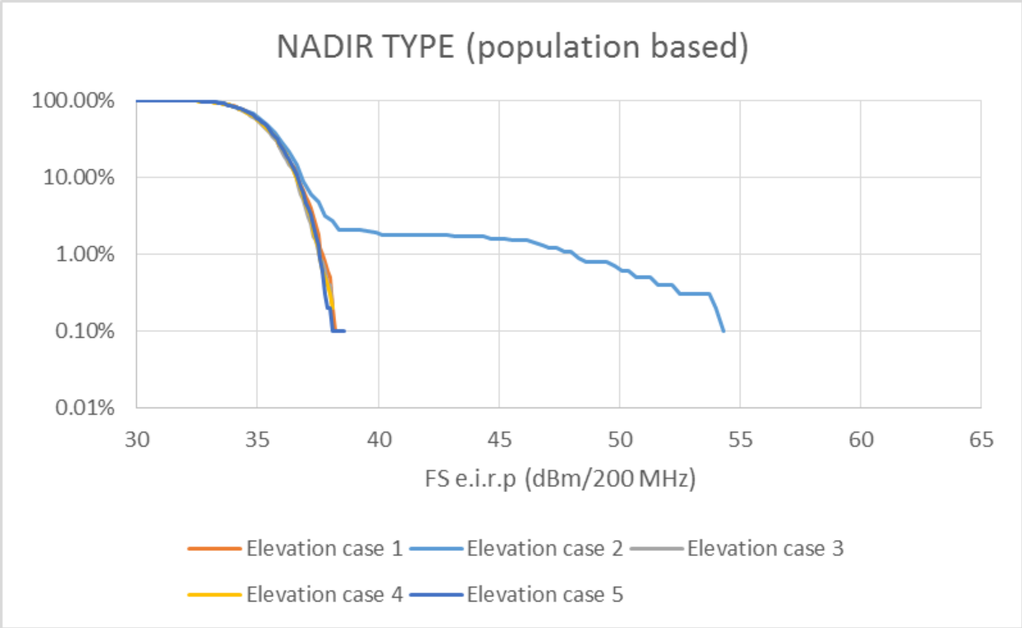


FIGURE A4-35

FS e.i.r.p. at the ground for NADIR type sensor (population based)



Maximum aggregate e.i.r.p. from Figures above = 38.6 dBm/200 MHz (not considering the peak from Case 2)

e) Aggregate case for the GOMAS type (nadir) sensor

FIGURE A4-36

FS e.i.r.p. at the ground for GOMAS type sensor (density based)

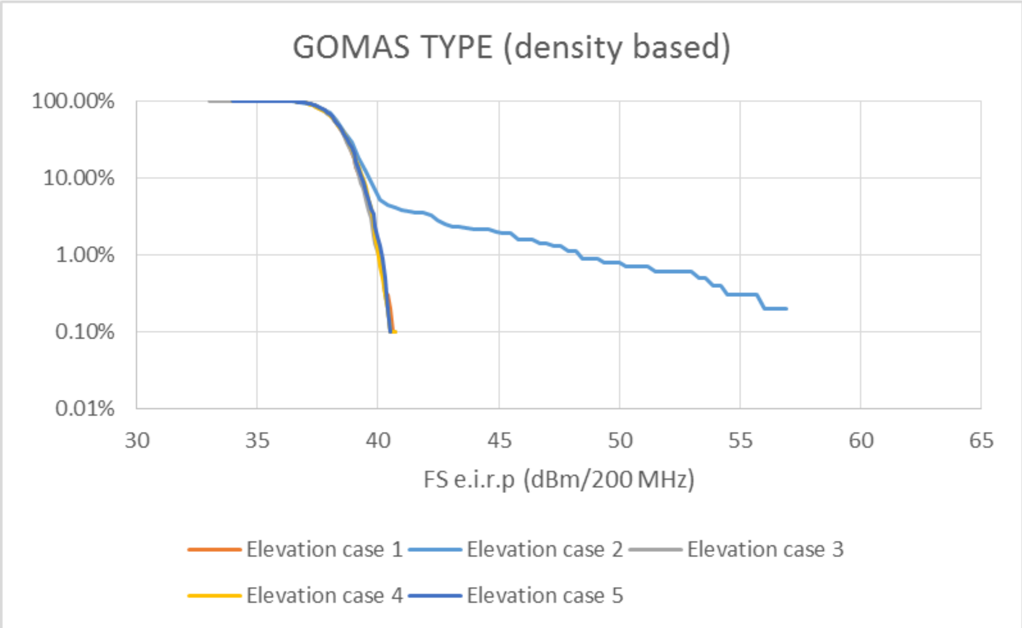
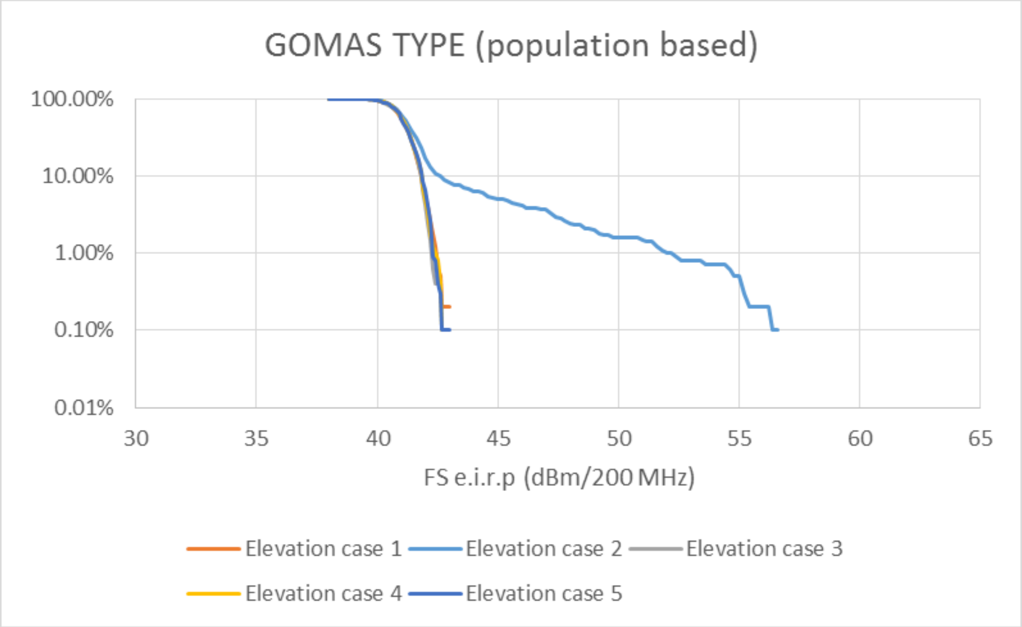


FIGURE A4-37

FS e.i.r.p. at the ground for GOMAS type sensor (population based)



Maximum aggregate e.i.r.p. from Figures above = 43 dBm/200 MHz (not considering the peak from Case 2).

f) Aggregate case for the GOMAS type (low) sensor

FIGURE A4-38

FS e.i.r.p. at the ground for GOMAS type (low) sensor (density based)

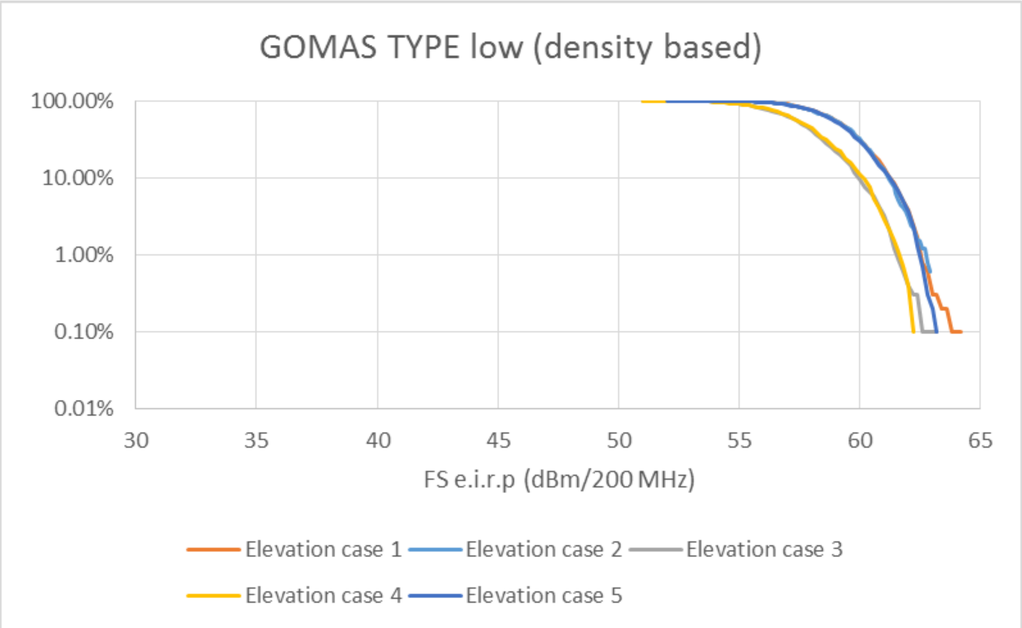
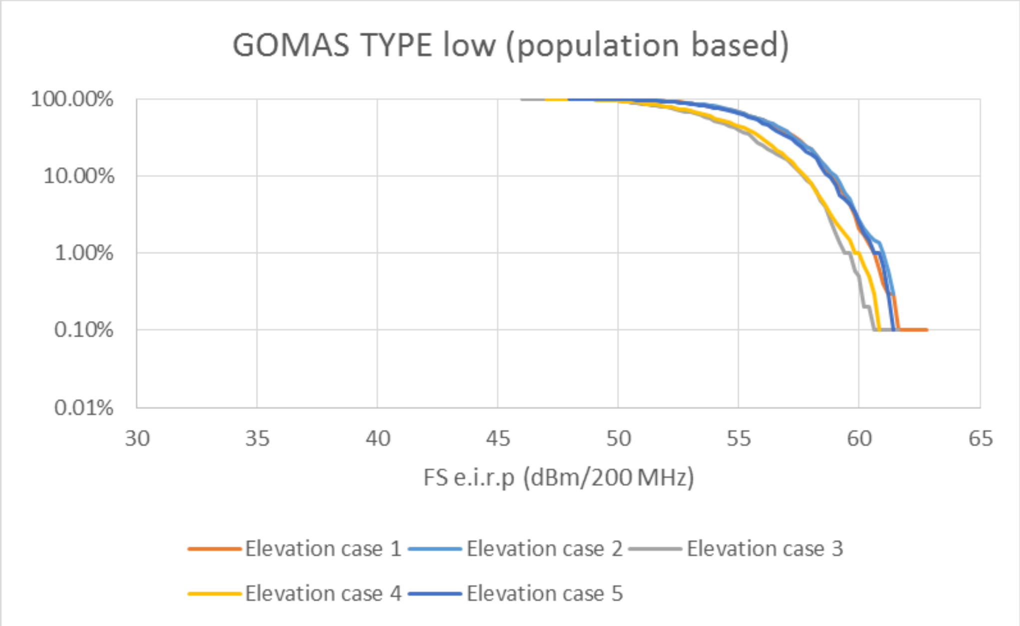


FIGURE A4-39

FS e.i.r.p. at the ground for GOMAS type (low) sensor (population based)



Maximum aggregate e.i.r.p. from Figures above = 64.2 dBm/200 MHz.

A4.6.4 Sharing studies with specific EESS (passive) system (ICI)

Table A4-13 provides the maximum e.i.r.p. at the ground in direction of the EESS (passive) satellites (expressed in dBm/200 MHz) in order to ensure protection of the ICI sensor in the 313-356 GHz band. The atmospheric losses have been calculated according to the model provided in Recommendation ITU-R P.676. The difference in atmospheric attenuation between the different channels described below is due to the variation in the water vapour profile versus frequency.

TABLE A4-13

Maximum interference at the ground for ICI system

EESS system	ICI-1L	ICI-2L	ICI-3L	ICI-4L	ICI-5L	ICI-6L
Frequency (GHz)	315.65	321.65	323.65	326.65	327.45	334.65
Type of sensor	conical	conical	conical	conical	conical	conical
Orbit altitude (km)	817	817	817	817	817	817
Nadir angle (degree)	53.0	53.0	53.0	53.0	53.0	53.0
Slant path distance (km)	1 563	1 563	1 563	1 563	1 563	1 563
Free space losses (dB)	206.3	206.5	206.5	206.6	206.6	206.8
Elevation at ground (degree)	25.7	25.7	25.7	25.7	25.7	25.7
Atmofpheric losses (dB)	22.4	48.4	90.3	92.5	65.2	28.1
Antenna gain (dBi)	55	55	55	55	55	55
Protection criteria (dBW/200 MHz)	-158	-158	-158	-158	-158	-158
Apportionment (dB)	3	3	3	3	3	3
Maximum interference at the ground (dBW/200 MHz)	42.7	68.9	110.8	113.1	85.8	48.9

According to the analysis in § A4.6.3 above, the following maximum FS e.i.r.p. at the ground are expected:

1) single entry = 60 dBm/200 MHz

2) aggregate = 59.8 dBm/200 MHz

Conclusions for ICI in the 313-356 GHz band

The above results shows that FS deployment will not be compatible with ICI operation considering its channels 1 and 6.

On the contrary, it shows that compatibility can be ensured with its channels 2 to 5.

A4.6.5 Generic analysis in all EESS (passive) bands

For each frequency band, the difference in free space losses at the lower and upper bound frequencies is assumed to be negligible. Analyses are hence made only at the centre frequency for each EESS (passive) frequency band.

On this basis, it is proposed to calculate, for each band and all five generic EESS (passive) sensors, the net maximum interference at the ground without considering the atmospheric attenuation.

Then, comparing this net level with the Maximum FS power at the ground (single entry and aggregate) calculated in § 4 above, allows to determine the minimum required level of atmospheric attenuation (at corresponding elevation) to ensure protection of the EESS (passive) sensors.

This level can then be used to determine the equivalent minimum zenithal atmospheric attenuation for comparison with the levels pertaining to each frequency bands determined according to Recommendation ITU-R P.676.

a) Frequency band 296-306 GHz

Table A4-14 provides the minimum zenithal atmospheric attenuation required to ensure protection of all types of sensors 296-306 GHz band.

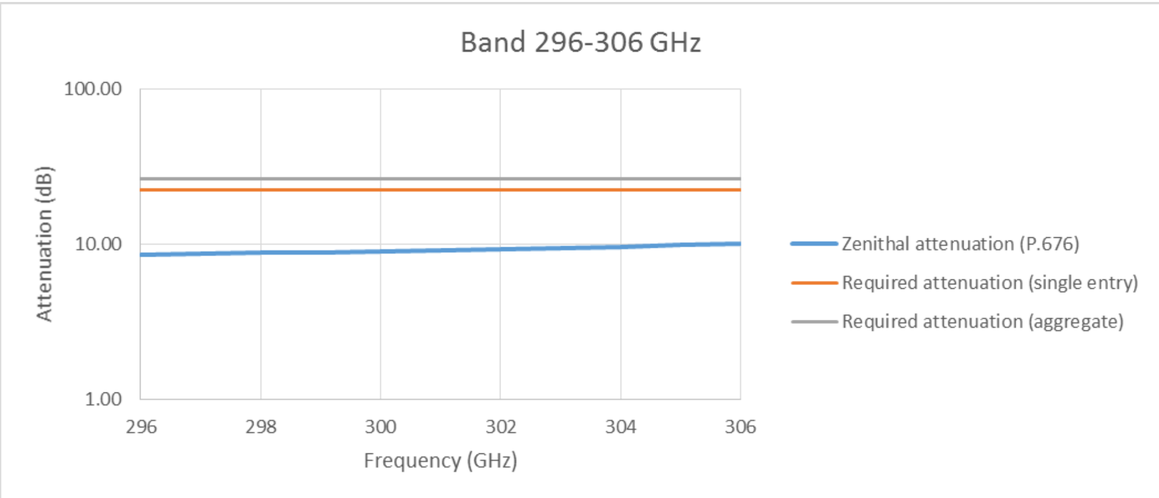
TABLE A4-14

Minimum zenithal atmospheric attenuation (296-306 GHz)

EESS system		ICI TYPE	TWICE TYPE	NADIR TYPE	GOMAS TYPE	GOMAS TYPE	
Center frequency	GHz	301	301	301	301	301	
Orbit altitude	km	817	400	817	35684	35684	
Nadir angle	°	53.0	53.0	0.0	0.0	8.5	
Slant path distance	km	1563	706	817	35684	40197	
Free Space losses	dB	205.9	199.0	200.3	233.1	234.1	
Elev at ground	°	25.7	31.9	90.0	90.0	12.7	
Atmospheric losses	dB						
Antenna gain	dBi	55	48	55	79	79	
Protection criteria	dBW/200 MHz	-160	-160	-160	-160	-160	
Apportionment	dB	3	3	3	3	3	
Maximum interference at the ground	**dBm/200 MHz**	**17.9**	**18.0**	**12.3**	**21.1**	**22.1**	
Maximum FS power at the ground (single entry)	dBW/200 MHz	60.0	60.0	60.0	60.0	60.0	
Maximum FS power at the ground (aggregate)	dBm/200 MHz	59.8	56.3	38.6	43.0	64.2	
Required Atmospheric attenuation (single entry)	dB	42.1	42.0	47.7	38.9	37.9	
Required Atmospheric attenuation (aggregate)	dB	41.9	38.3	26.3	21.9	42.1	**MAX**
Equivalent required zenithal atmospheric attenuation (single entry)	**dB**	**18.3**	**22.2**			**8.3**	**22.2**
Equivalent required zenithal atmospheric attenuation (aggregate)	**dB**	**18.2**	**20.3**	**26.3**	**21.9**	**9.2**	**26.3**

FIGURE A4-40

Comparison between required and P.676 attenuations (296-306 GHz)



This Figure shows that the atmospheric attenuation in the band 296-306 GHz band is not sufficient to ensure protection of EESS (passive).

The 296-306 GHz band therefore cannot be used for the FS without specific conditions.

b) Frequency band 313-356 GHz

Table A4-15 provides the minimum zenithal atmospheric attenuation required to ensure protection of all types of sensors 313-356 GHz band.

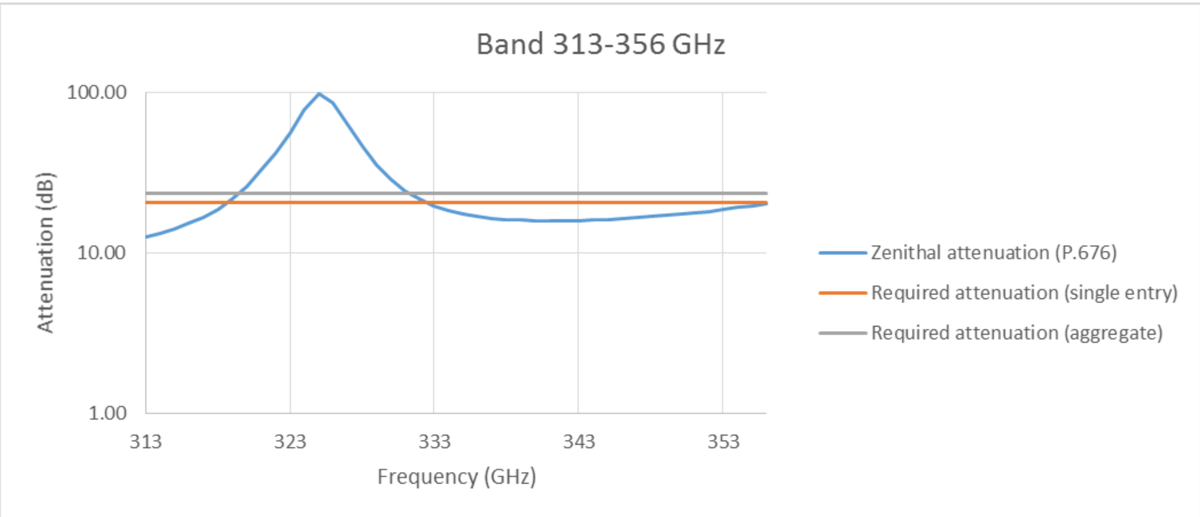
TABLE A4-15

Minimum zenithal atmospheric attenuation (313-356 GHz)

EESS system		ICI TYPE	TWICE TYPE	NADIR TYPE	GOMAS TYPE	GOMAS TYPE	
Center frequency	GHz	334.5	334.5	334.5	334.5	334.5	
Orbit altitude	km	817	400	817	35684	35684	
Nadir angle	°	53.0	53.0	0.0	0.0	8.5	
Slant path distance	km	1563	706	817	35684	40197	
Free Space losses	dB	206.8	199.9	201.2	234.0	235.0	
Elev at ground	°	25.7	31.9	90.0	90.0	12.7	
Atmospheric losses	dB						
Antenna gain	dBi	55	48	55	79	79	
Protection criteria	dBW/200 MHz	-158	-158	-158	-158	-158	
Apportionment	dB	3	3	3	3	3	
Maximum interference at the ground	**dBm/200 MHz**	**20.8**	**20.9**	**15.2**	**24.0**	**25.0**	
Maximum FS power at the ground (single entry)	dBW/200 MHz	60.0	60.0	60.0	60.0	60.0	
Maximum FS power at the ground (aggregate)	dBm/200 MHz	59.8	56.3	38.6	43.0	64.2	
Required Atmospheric attenuation (single entry)	dB	39.2	39.1	44.8	36.0	35.0	
Required Atmospheric attenuation (aggregate)	dB	39.0	35.4	23.4	19.0	39.2	**MAX**
Equivalent required zenithal atmospheric attenuation (single entry)	**dB**	**17.0**	**20.7**			**7.7**	**20.7**
Equivalent required zenithal atmospheric attenuation (aggregate)	**dB**	**16.9**	**18.7**	**23.4**	**19.0**	**8.6**	**23.4**

FIGURE A4-41

Comparison between required and P.676 attenuations (313-356 GHz)



This Figure shows that the atmospheric attenuation in most of the band 313-356 GHz band is not sufficient to ensure protection of EESS (passive).

However, the 320-331 GHz band (11 GHz width) could be used for FS applications.

c) Frequency band 361-365 GHz

Table A4-16 provides the minimum zenithal atmospheric attenuation required to ensure protection of all types of sensors 361-365 GHz band.

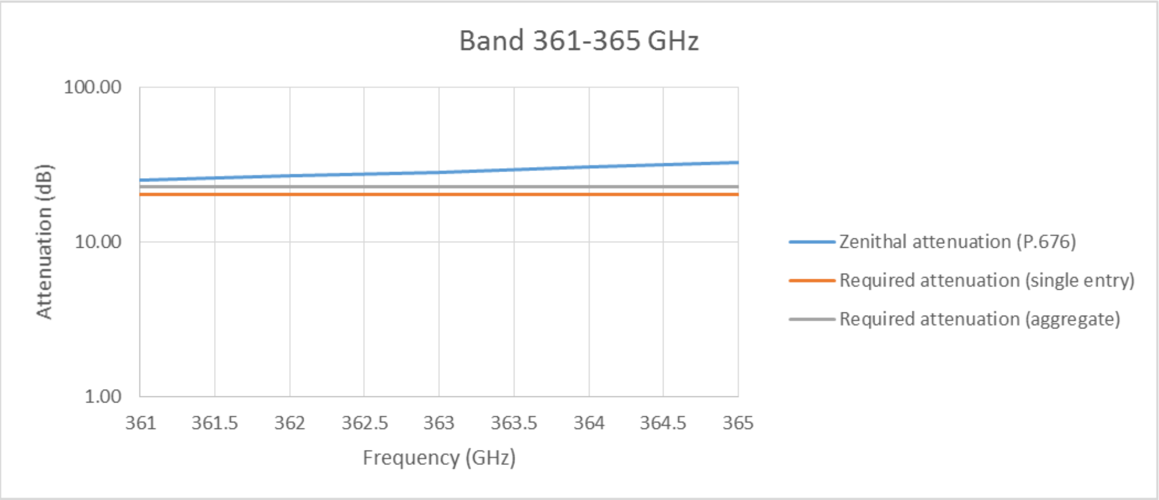
TABLE A4-16

Minimum zenithal atmospheric attenuation (361-365 GHz)

EESS system		ICI TYPE	TWICE TYPE	NADIR TYPE	GOMAS TYPE	GOMAS TYPE	
Center frequency	GHz	363	363	363	363	363	
Orbit altitude	km	817	400	817	35684	35684	
Nadir angle	°	53.0	53.0	0.0	0.0	8.5	
Slant path distance	km	1563	706	817	35684	40197	
Free Space losses	dB	207.5	200.6	201.9	234.7	235.7	
Elev at ground	°	25.7	31.9	90.0	90.0	12.7	
Atmospheric losses	dB						
Antenna gain	dBi	55	48	55	79	79	
Protection criteria	dBW/200 MHz	-158	-158	-158	-158	-158	
Apportionment	dB	3	3	3	3	3	
Maximum interference at the ground	**dBm/200 MHz**	**21.5**	**21.6**	**15.9**	**24.7**	**25.7**	
Maximum FS power at the ground (single entry)	dBW/200 MHz	60.0	60.0	60.0	60.0	60.0	
Maximum FS power at the ground (aggregate)	dBm/200 MHz	59.8	56.3	38.6	43.0	64.2	
Required Atmospheric attenuation (single entry)	dB	38.5	38.4	44.1	35.3	34.3	
Required Atmospheric attenuation (aggregate)	dB	38.3	34.7	22.7	18.3	38.5	**MAX**
Equivalent required zenithal atmospheric attenuation (single entry)	**dB**	**16.7**	**20.3**			**7.5**	**20.3**
Equivalent required zenithal atmospheric attenuation (aggregate)	**dB**	**16.6**	**18.3**	**22.7**	**18.3**	**8.4**	**22.7**

FIGURE A4-42

Comparison between required and P.676 attenuations (361-365 GHz)



This Figure shows that the atmospheric attenuation in the band 361-365 GHz is sufficient to ensure protection of EESS (passive).

The 361-365 GHz band could be used for FS applications.

d) Frequency band 369-392 GHz

Table A4-17 provides the minimum zenithal atmospheric attenuation required to ensure protection of all types of sensors 369-392 GHz band.

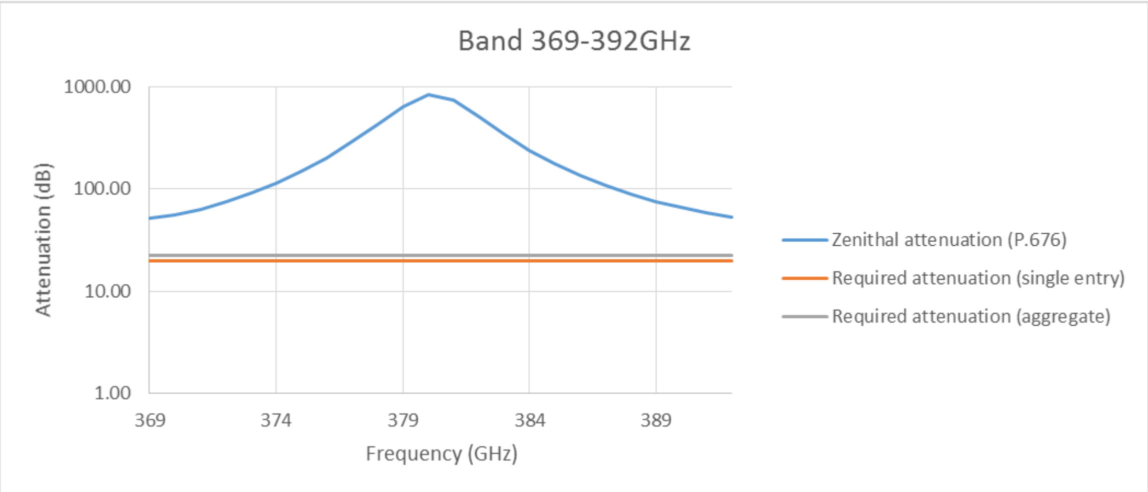
TABLE A4-17

Minimum zenithal atmospheric attenuation (369-392 GHz)

EESS system		ICI TYPE	TWICE TYPE	NADIR TYPE	GOMAS TYPE	GOMAS TYPE	
Center frequency	GHz	380.5	380.5	380.5	380.5	380.5	
Orbit altitude	km	817	400	817	35684	35684	
Nadir angle	°	53.0	53.0	0.0	0.0	8.5	
Slant path distance	km	1563	706	817	35684	40197	
Free Space losses	dB	207.9	201.0	202.3	235.1	236.1	
Elev at ground	°	25.7	31.9	90.0	90.0	12.7	
Atmospheric losses	dB						
Antenna gain	dBi	55	48	55	79	79	
Protection criteria	dBW/200 MHz	-158	-158	-158	-158	-158	
Apportionment	dB	3	3	3	3	3	
Maximum interference at the ground	**dBm/200 MHz**	**21.9**	**22.0**	**16.3**	**25.1**	**26.1**	
Maximum FS power at the ground (single entry)	dBW/200 MHz	60.0	60.0	60.0	60.0	60.0	
Maximum FS power at the ground (aggregate)	dBm/200 MHz	59.8	56.3	38.6	43.0	64.2	
Required Atmospheric attenuation (single entry)	dB	38.1	38.0	43.7	34.9	33.9	
Required Atmospheric attenuation (aggregate)	dB	37.9	34.3	22.3	17.9	38.1	**MAX**
Equivalent required zenithal atmospheric attenuation (single entry)	**dB**	**16.5**	**20.1**			**7.4**	**20.1**
Equivalent required zenithal atmospheric attenuation (aggregate)	**dB**	**16.4**	**18.1**	**22.3**	**17.9**	**8.3**	**22.3**

FIGURE A4-43

Comparison between required and P.676 attenuations (369-392 GHz)



This Figure shows that the atmospheric attenuation in the band 369-392 GHz is sufficient to ensure protection of EESS (passive).

The 369-392 GHz band could be used for FS applications.

e) Frequency band 397-399 GHz

Table A4-18 provides the minimum zenithal atmospheric attenuation required to ensure protection of all types of sensors 397-399 GHz band.

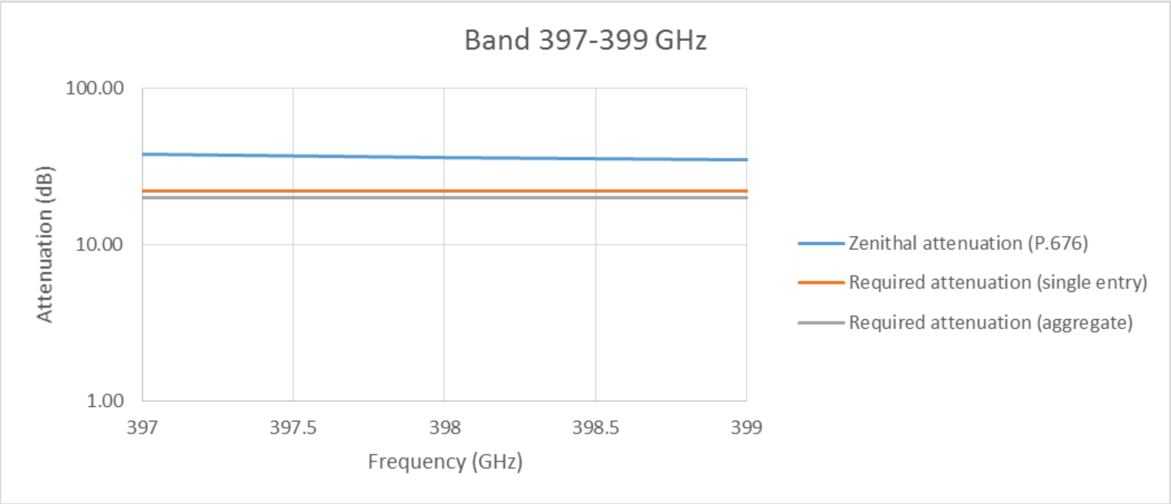
TABLE A4-18

Minimum zenithal atmospheric attenuation (392-399 GHz)

EESS system		ICI TYPE	TWICE TYPE	NADIR TYPE	GOMAS TYPE	GOMAS TYPE	
Center frequency	GHz	398	398	398	398	398	
Orbit altitude	km	817	400	817	35684	35684	
Nadir angle	°	53.0	53.0	0.0	0.0	8.5	
Slant path distance	km	1563	706	817	35684	40197	
Free Space losses	dB	208.3	201.4	202.7	235.5	236.5	
Elev at ground	°	25.7	31.9	90.0	90.0	12.7	
Atmospheric losses	dB						
Antenna gain	dBi	55	48	55	79	79	
Protection criteria	dBW/200 MHz	-158	-158	-158	-158	-158	
Apportionment	dB	3	3	3	3	3	
Maximum interference at the ground	**dBm/200 MHz**	**22.3**	**22.4**	**16.7**	**25.5**	**26.5**	
Maximum FS power at the ground (single entry)	dBW/200 MHz	60.0	60.0	60.0	60.0	60.0	
Maximum FS power at the ground (aggregate)	dBm/200 MHz	59.8	56.3	38.6	43.0	64.2	
Required Atmospheric attenuation (single entry)	dB	37.7	37.6	43.3	34.5	33.5	
Required Atmospheric attenuation (aggregate)	dB	37.5	33.9	21.9	17.5	37.7	**MAX**
Equivalent required zenithal atmospheric attenuation (single entry)	**dB**	**16.3**	**19.9**			**7.3**	**19.9**
Equivalent required zenithal atmospheric attenuation (aggregate)	**dB**	**16.3**	**17.9**	**21.9**	**17.5**	**8.3**	**21.9**

FIGURE A4-44

Comparison between required and P.676 attenuations (397-399 GHz)



This Figure shows that the atmospheric attenuation in the band 397-399 GHz is sufficient to ensure protection of EESS (passive).

The 397-399 GHz band could be used for FS applications.

f) Frequency band 416-434 GHz

Table A4-19 provides the minimum zenithal atmospheric attenuation required to ensure protection of all types of sensors 416-434 GHz band.

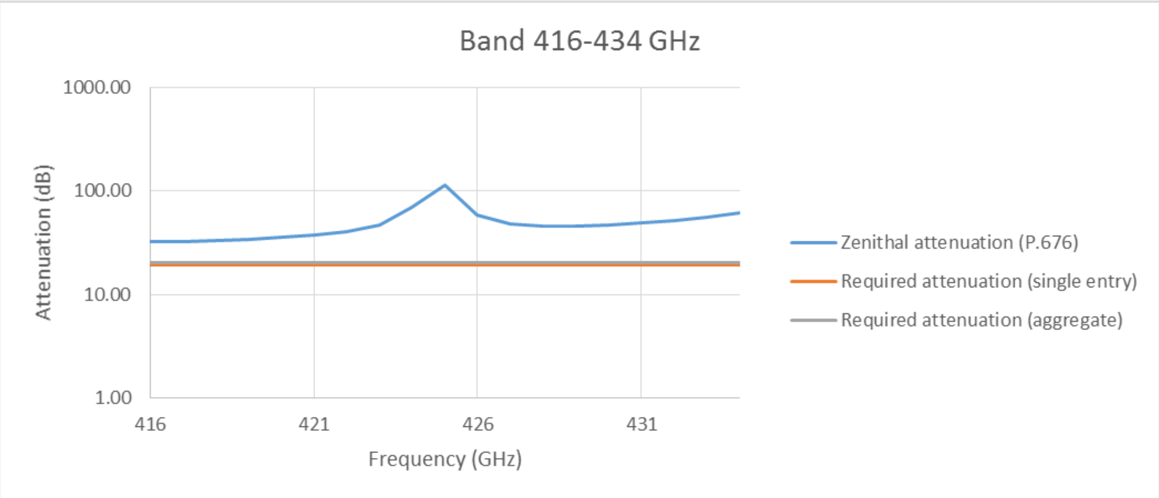
TABLE A4-19

Minimum zenithal atmospheric attenuation (416-434 GHz)

EESS system		ICI TYPE	TWICE TYPE	NADIR TYPE	GOMAS TYPE	GOMAS TYPE	
Center frequency	GHz	425	425	425	425	425	
Orbit altitude	km	817	400	817	35684	35684	
Nadir angle	°	53.0	53.0	0.0	0.0	8.5	
Slant path distance	km	1563	706	817	35684	40197	
Free Space losses	dB	208.9	202.0	203.3	236.1	237.1	
Elev at ground	°	25.7	31.9	90.0	90.0	12.7	
Atmospheric losses	dB						
Antenna gain	dBi	55	48	55	79	79	
Protection criteria	dBW/200 MHz	-157	-157	-157	-157	-157	
Apportionment	dB	3	3	3	3	3	
Maximum interference at the ground	**dBm/200 MHz**	**23.9**	**24.0**	**18.3**	**27.1**	**28.1**	
Maximum FS power at the ground (single entry)	dBW/200 MHz	60.0	60.0	60.0	60.0	60.0	
Maximum FS power at the ground (aggregate)	dBm/200 MHz	59.8	56.3	38.6	43.0	64.2	
Required Atmospheric attenuation (single entry)	dB	36.1	36.0	41.7	32.9	31.9	
Required Atmospheric attenuation (aggregate)	dB	35.9	32.3	20.3	15.9	36.1	**MAX**
Equivalent required zenithal atmospheric attenuation (single entry)	**dB**	**15.7**	**19.0**			**7.0**	**19.0**
Equivalent required zenithal atmospheric attenuation (aggregate)	**dB**	**15.6**	**17.1**	**20.3**	**15.9**	**7.9**	**20.3**

FIGURE A4-45

Comparison between required and P.676 attenuations (416-434 GHz)



This Figure shows that the atmospheric attenuation in the band 416-434 GHz is sufficient to ensure protection of EESS (passive).

The 416-434 GHz band could be used for FS applications.

g) Frequency band 439-467 GHz

Table A4-20 provides the minimum zenithal atmospheric attenuation required to ensure protection of all types of sensors 439-467 GHz band.

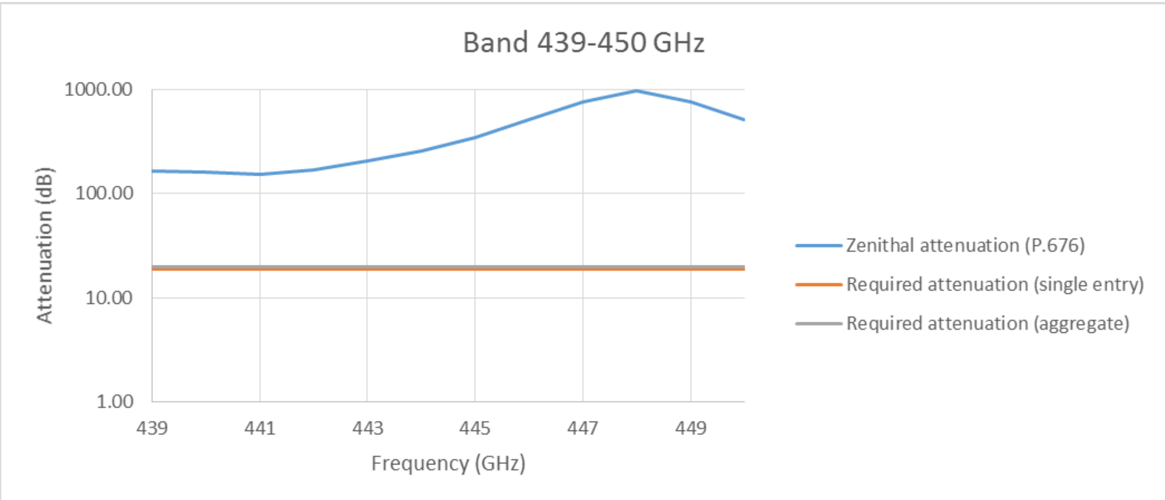
TABLE A4-20

Minimum zenithal atmospheric attenuation (439-467 GHz)

EESS system		ICI TYPE	TWICE TYPE	NADIR TYPE	GOMAS TYPE	GOMAS TYPE	
Center frequency	GHz	453	453	453	453	453	
Orbit altitude	km	817	400	817	35684	35684	
Nadir angle	°	53.0	53.0	0.0	0.0	8.5	
Slant path distance	km	1563	706	817	35684	40197	
Free Space losses	dB	209.4	202.5	203.8	236.6	237.6	
Elev at ground	°	25.7	31.9	90.0	90.0	12.7	
Atmospheric losses	dB						
Antenna gain	dBi	55	48	55	79	79	
Protection criteria	dBW/200 MHz	-157	-157	-157	-157	-157	
Apportionment	dB	3	3	3	3	3	
Maximum interference at the ground	**dBm/200 MHz**	**24.4**	**24.5**	**18.8**	**27.6**	**28.6**	
Maximum FS power at the ground (single entry)	dBW/200 MHz	60.0	60.0	60.0	60.0	60.0	
Maximum FS power at the ground (aggregate)	dBm/200 MHz	59.8	56.3	38.6	43.0	64.2	
Required Atmospheric attenuation (single entry)	dB	35.6	35.5	41.2	32.4	31.4	
Required Atmospheric attenuation (aggregate)	dB	35.4	31.8	19.8	15.4	35.6	**MAX**
Equivalent required zenithal atmospheric attenuation (single entry)	**dB**	**15.4**	**18.7**			**6.9**	**18.7**
Equivalent required zenithal atmospheric attenuation (aggregate)	**dB**	**15.3**	**16.8**	**19.8**	**15.4**	**7.8**	**19.8**

FIGURE A4-46

Comparison between required and P.676 attenuations (439-450 GHz)



This Figure shows that the atmospheric attenuation in the band 439-450 GHz is sufficient to ensure protection of EESS (passive).

The 439-450 GHz band could be used for FS applications.

A4.6.6 Summary of Study 5

Overall, within the 275-450 GHz band, the following bands currently identified for EESS (passive) in RR No. **5.565** cannot be made available to the FS:

– 296-306 GHz

– 313-320 GHz

– 331-356 GHz

In the remaining parts of the 275-450 GHz range, FS usage can be envisaged.

Considering the potential FS targeted bands (275-320 GHz, 330-370 GHz and 380-445 GHz), the following bands would hence be available for FS usage:

– 275-296 GHz (21 GHz width), allowing for a continuous FS spectrum block of 44 GHz width together with the band 252-275 GHz already allocated to FS

– 306-313 GHz (7 GHz width)

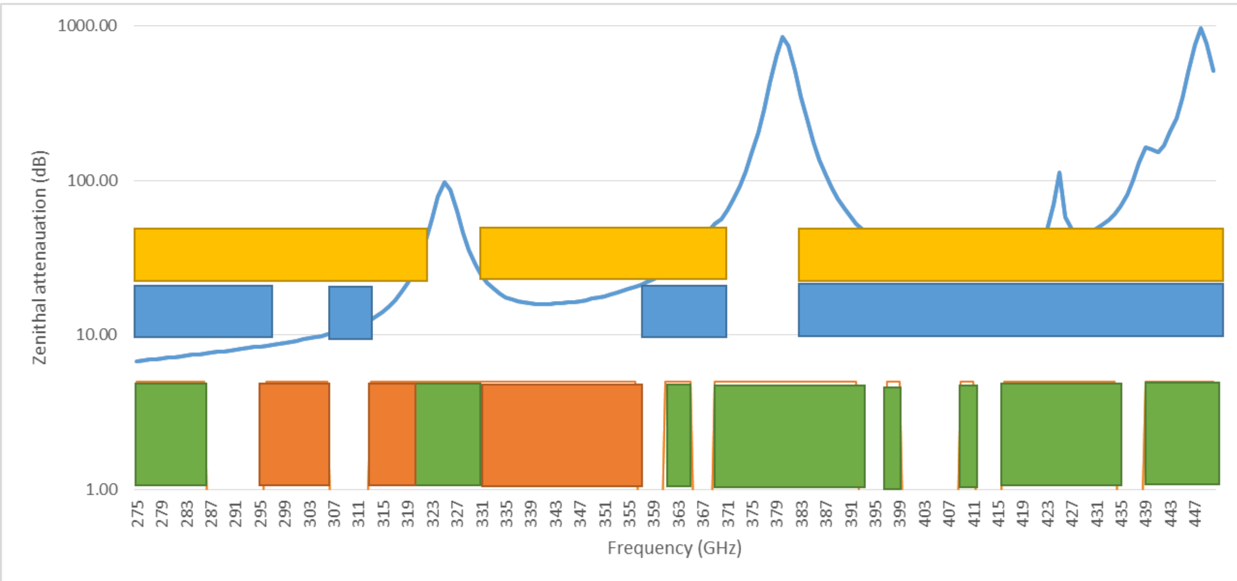
– 356-370 GHz (14 GHz width)

– 380-445 GHz (65 GHz width)

These bands would be far enough to accommodate FS spectrum requirements (50 GHz).

The situation can be summarised by Fig. A4-47.

FIGURE A4-47



EESS (passive) band in which sharing with FS is not possible
EESS (passive) band in which sharing with FS is possible
targeted FS bands
bands for which an FS identification is possible

A4.6.7 Annex 1 to Study 5 – Methodolgy used to derive number of fs links on a population based deployment

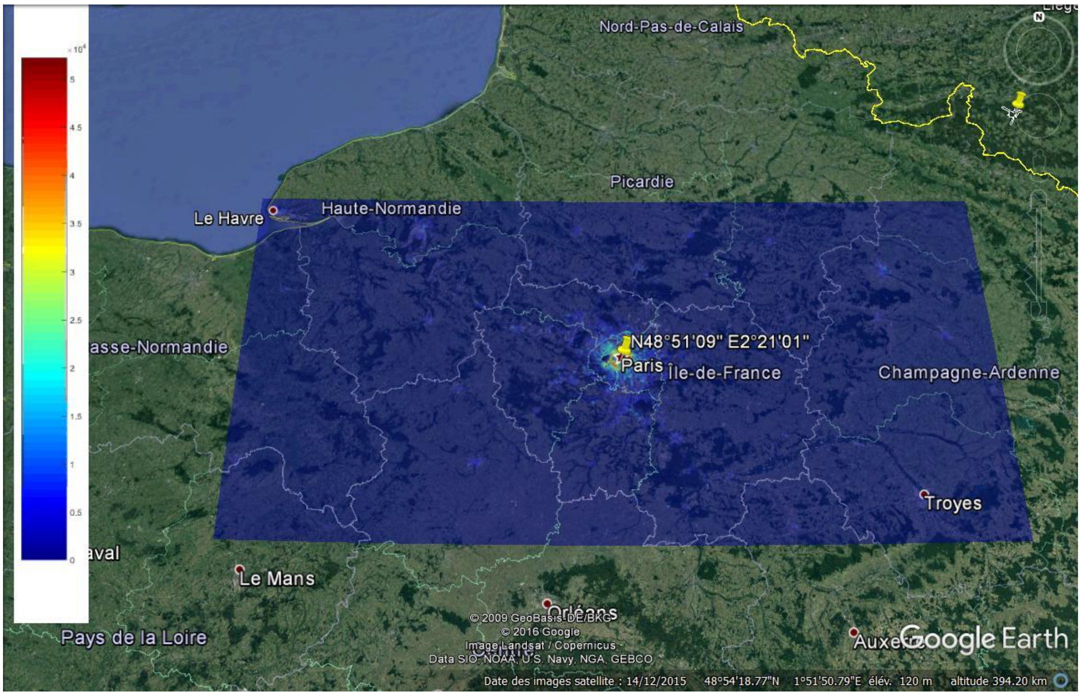
A4.6.7.1 Specific area of study

The area of study has been specified as follows:

– Centred on Paris (France)
– 340 km East to West
– 161 km South to North
– Total area of 54 740 km²

This area is described in Fig. A4-48 below.

FIGURE A4-48



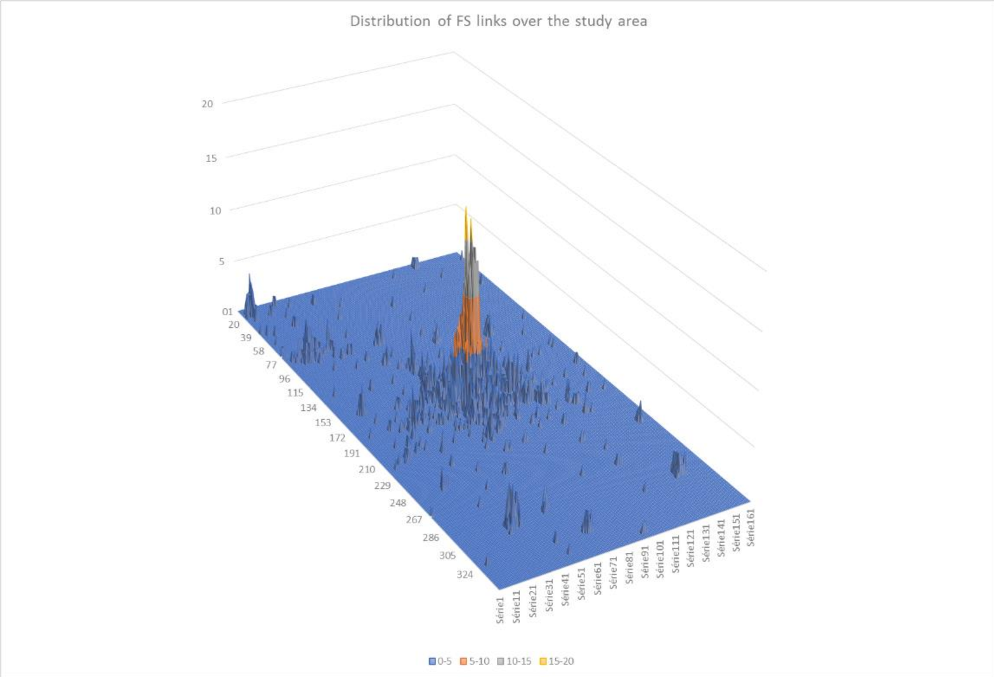
A4.6.7.2 Spatial distribution of FS links

Taking into account the above elements, the FS links are distributed in the study area.

For each km², the number of FS links is determined by multiplying the number of inhabitant by the FS density/inhabitant (i.e. 0.000351), the final figure being rounded to the closest integer.

In total, 4 415 FS links are distributed in the study area. Figure A4-49 depicts the spatial distribution of these FS links over the study area.

FIGURE A4-49



A4.6.7.3 Distribution of FS links in the EESS (passive) footprints

For each of the EESS (passive) sensor, the number of FS links in the footprint is determined by placing the footprint at the centre of the study area.

Figure A4-50 depicts the spatial distribution of the FS links over the EESS (passive) footprint, taking the example of System "GOMAS (low)". It leads to a number of 1 903 FS links deployed over its footprint.

FIGURE A4-50

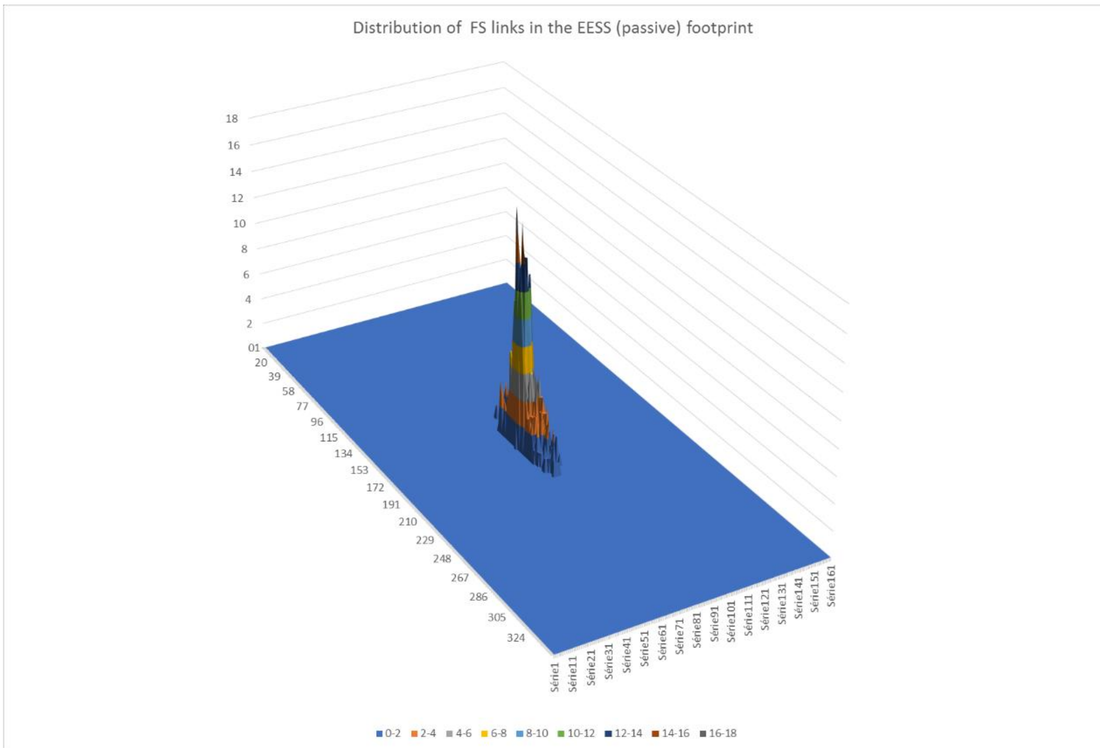


Table A4-21 provides the number of FS links within the footprint of each EESS (passive) system.

TABLE A4-21

	ICI Type	**TWICE Type**	**NADIR Type**	**GOMAS Type (Nadir)**	**GOMAS Type (low elevation)**
IFOV (km²)	200	50	30	110	890
Population based (Nb of links)	1 030	393	228	874	1 903

Annex 5

Sharing studies between FS applications and radio astronomy service

A5.1 Introduction

Report ITU-R RA.2189-1, which addressed sharing between the radio astronomy service and active services in the frequency range 275-3 000 GHz, concluded that sharing between radio astronomy and active services in this frequency range is possible if atmospheric characteristics as a function of height above sea level, as well as transmitter antenna directivity, are taken into account. The Report noted that RAS sites are typically located at high altitudes with significantly lower atmospheric attenuation than at sea level, and highlighted the importance of case-by-case evaluation of sharing situations. Direct illumination of radio astronomy sites by transmitters close to sea level, if geometrically possible, would likely involve far greater atmospheric absorption effects, and therefore decreased geographic separation requirements for a given transmitter power. This Report did not separately consider LMS and FS applications, but only considered a single transmitter power level from a generic active service. More detailed sharing studies, including aggregate impacts, may be necessary if large numbers are envisioned. This Annex evaluates the feasibility of sharing between the RAS and FS and LMS applications in the frequency bands identified for RAS use in RR No. **5.565** based on the specific parameters provided in § 5 of this Report.

A5.2 Study 1: Compatibility between RAS and FS operations in the spectrum band 275-450 GHz

A5.2.1 Assumptions and geometries

For the FS (see Report ITU-R SM.2450 (“the Report”), Table 7, Section 5.2.1):

FS power output: 0-20 dBm

FS bandwidth: 24 GHz

FS antenna pattern: Recommendation ITU-R F.699-7, $D/\lambda > 100$, peak gain 50 dBi

FS peak e.i.r.p.: 50-70 dBm

Assumptions used for propagation

Recommendation ITU-R P.676-11: a spectral line by line atmospheric attenuation calculation was performed (see Fig. 5.1-1).

Measured properties at the ALMA telescope at h=4.8 km were used to define input parameters to Recommendation ITU-R P.676: T=273K; pHa = 551; e(pH_2O) = 1.14. The measured zenith attenuation at 345 GHz, combined with the procedure to determine the zenith attenuation from a given ambient specific attenuation at frequencies below 350 GHz (Recommendation ITU-R P.676 Section 2.2), was used to derive the ambient specific attenuation (dB/km) at the ALMA site as shown in Fig. A5-1.

Scaling to h = 2.8 km and to h = 0 was performed using standard dry air scale height 8.4 km and H_2O scale height 2 km as given in P.676 for lower elevations.

Line of sight geometries without clutter or building entry loss were used.

Radio Astronomy protection criteria (see § 5.3)

Input power thresholds from Table 9, col. 8 with linear interpolation in frequency

RAS receiver bandwidth: 8 GHz; only 1/3 of the FS power is received by RAS

NB: RAS protection criteria are referred to 0 dBi gain and do not depend on the orientation or beam pattern of the RAS antenna.

Choice of frequencies

275 GHz to illustrate the high transparency at the lower end of the band. Considerations at this frequency apply equally to compatibility with RAS operations in the immediately adjacent bands below 275 GHz (Report section 7.2.7).

345 GHz because it is of paramount interest to RAS, being the rest frequency of the J = 3-2 transition of carbon monoxide, CO

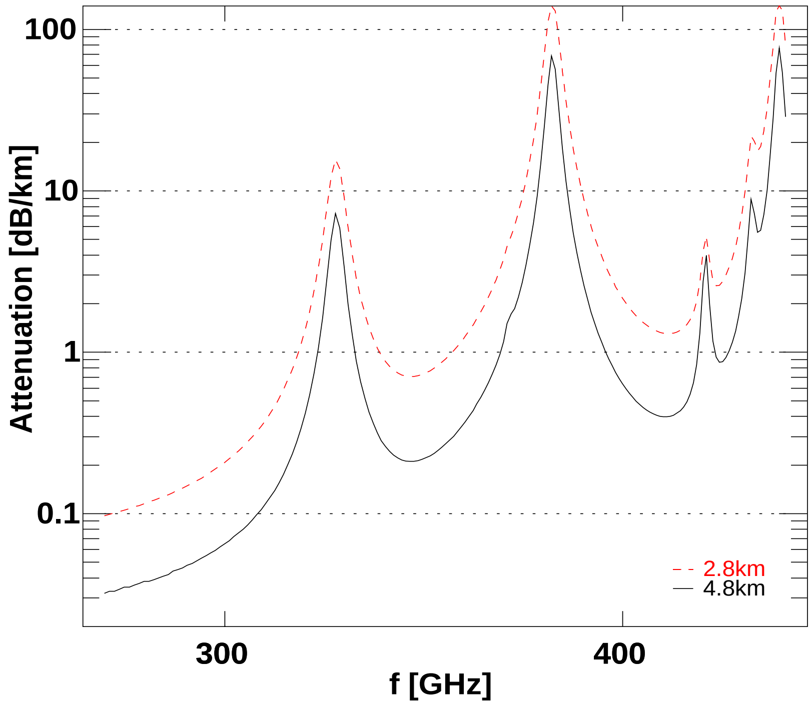
412 GHz to illustrate use of a frequency near the upper end of the band that is in an atmospheric window

Geometry:

Two geometries are considered. At left in Fig. A5-2 (for the geometry) and Fig. A5-3 (for the propagation results), RAS and FS operations are on the same plane on flat ground, the FS beam is horizontal and varying FS azimuthal angles with respect to the RAS antenna are considered. For each azimuthal angle the minimum distance is calculated that is consistent with the RAS protection criteria, given the spreading loss, FS antenna gain and specific attenuation dB/km. At right in Fig. A5-2 and Fig. A5-3, RAS operations are at height h and FS operations are at height 0. The FS beam is fixed at the azimuth of the RAS operation and moves up and down. At each horizontal separation, the maximum elevation angle of the FS antenna is calculated, consistent with the RAS protection criteria. Where no compatible solution is possible, nothing is plotted.

FIGURE A5-1

Atmospheric specific attenuation at two elevations



The curve for elevation 4.8 km was determined from the measured zenith opacity at the ALMA telescope at that elevation. The curve for elevation 2.8 km was scaled from the ALMA result using standard atmospheric scale heights.

A5.2.2 Results

A5.2.2.1 Co-height operation

Results are shown at left in Fig. A5-3 for the geometry illustrated in Fig. A5-2 at left where FS and RAS operate at the same altitude: The ALMA and South Pole sites are large enough to make this feasible and clutter is not present at these arid sites. The calculation is simple; the specific attenuation (dB/km) is constant along the line of sight separating the RAS and FS operations and at each azimuthal FS beam angle a root solver iterates to find the distance at which the compatibility criteria are met, given the relevant beam pattern from Recommendation ITU-R F.699.

When the FS beam is directed at the RAS operation, large separation distances are required in all cases. Separation distances below 10 km are possible when the FS beam is directed more than about 10^o – 40^o away from the RAS operation.

Figure A5-4 shows the effect of varying the input power to the FS antenna. When the FS beam is oriented near the RAS operation, separation distances are large, path loss is dominated by atmospheric attenuation and the required separation distance decreases slowly as the power is reduced.

A5.2.2.2 High-elevation operation for RAS only

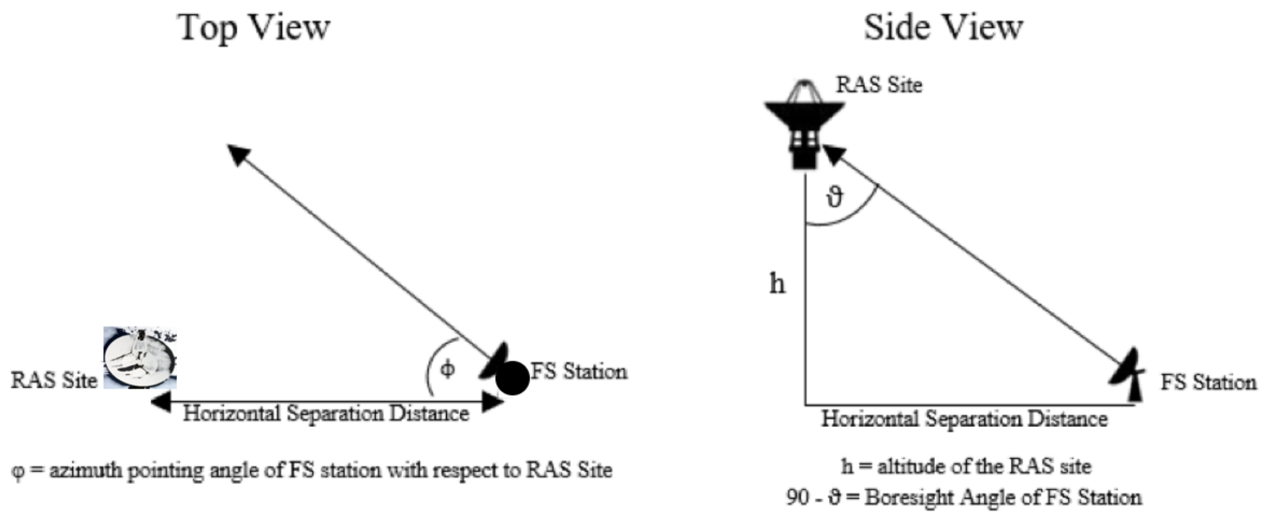
Results are shown at right in Fig. A5-3 for the geometry illustrated in Fig. A5-2 at right. In this arrangement, the radio telescope is at an altitude of h = 2.8 or h = 4.8 km and the FS operation is at altitude h = 0. The FS beam is directed azimuthally at the RAS operation and the FS beam elevation is allowed to vary up to a maximum value that is determined numerically and shown as the vertical axis at right in Fig. A5-3. The attenuation is calculated by numerically integrating along the slant path between the FS and RAS operations, using the standard scale heights for the dry and water vapour components of the atmosphere in Recommendation ITU-R P.676.

With increasing horizontal separation there is competition when the combined effects of increasing free-space spreading loss and atmospheric attenuation are counteracted because the RAS operation is seen closer to the boresight of a horizontally-directed FS beam.

RAS operations at high elevation are shielded from FS operations at zero elevation at 412 GHz: FS and RAS operations are compatible at all horizontal separations and FS beam elevations. At 275 GHz, FS and RAS operations are compatible only when the horizontal separation exceeds 60 km. In the intermediate frequency the FS operation requires a separation distance slightly larger than 1 km for the lower elevation RAS operation at h = 2.8 km.

FIGURE A5-2

Explanation of geometries used in Fig. A5-3

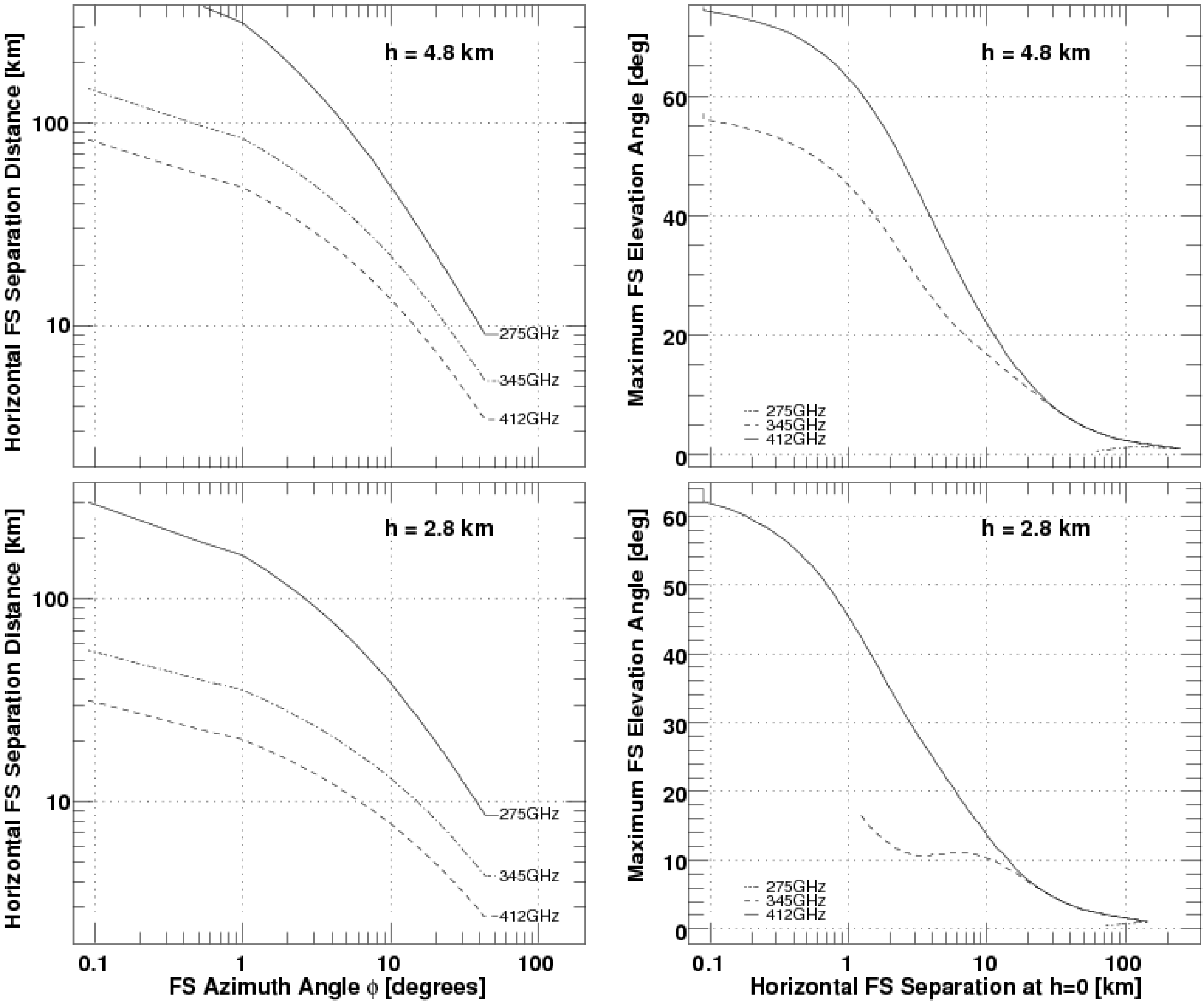


Left: Top view, for the geometry used in Fig. A5-3 at left. RAS and FS operations are on the same geographic elevation, the FS beam is horizontal and directed at an azimuthal angle ϕ with respect to the radio telescope.

Right: side view of the mountainside geometry used in Fig. A5-3 at right. RAS operations are at height h and FS operations are at h = 0, the FS beam is directed at the RAS operation azimuthally and the telescope is seen at a boresight angle 90-θ when the FS beam is horizontal.

FIGURE A5-3

Results of calculations for the geometries shown in Fig. A5-2

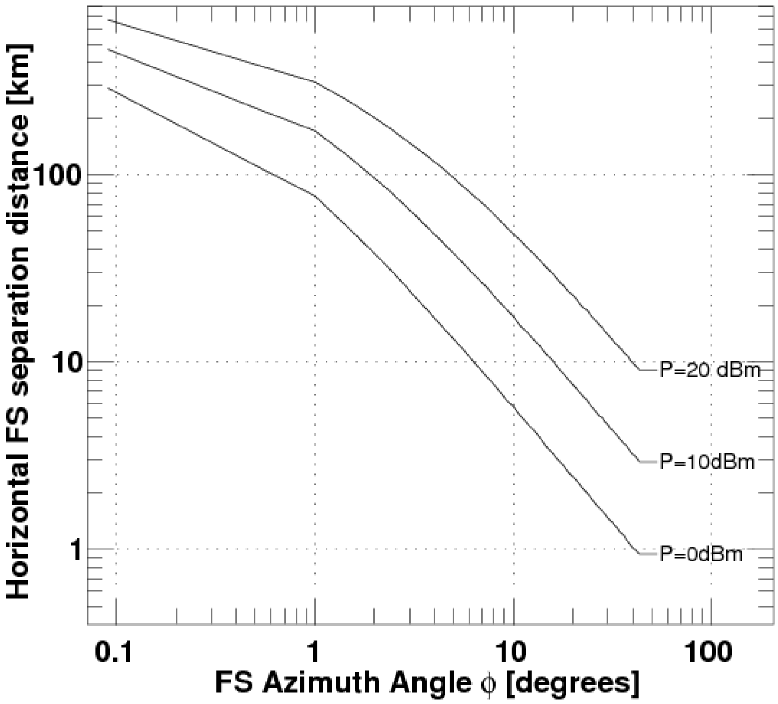


Left: For the geometry shown in Fig. A5-2 at left where the FS and RAS operations are at the same elevation and the FS beam is kept horizontal while variable in azimuth. The required separation distance is shown as a function of the azimuthal FS angle with respect to the RAS antenna. Shown are results at elevation 4.8 km at top and elevation 2.8 km at bottom, in both cases for frequencies 275, 345 and 412 GHz.

Right: For the geometry shown in Fig. A5-2 at right where the FS operation is at geographic elevation 0 and the RAS operation is at elevation h = 4.8 km (top) or h = 2.8 km (bottom) and the azimuthal angle of the FS antenna is 0 with respect to the RAS operation. Shown is the maximum allowed FS beam elevation angle at each horizontal separation: where no compatible solution is possible, nothing is plotted. The frequency 275 GHz shows the most restrictive use. At h = 2.8 km, FS elevation angle should be limited to 10 degrees for horizontal FS separation greater than 11 km. However, at h = 4.8 km, height varies from 45 degrees (separation of 1 km) to about 10 degrees (separation of about 20 km).Further results of calculations for the geometries shown in Fig. A5-2.

FIGURE A5-4

Further results of calculations for the geometries shown in Fig. A5-2. The calculation at upper left in Fig. A5-3 at h = 4.8 km and f = 275 GHz is repeated for FS input power 0, 10 and 20 dBm with 50 dBi peak FS antenna gain



The calculation at upper left in Fig. A5-3 at h = 4.8 km and f = 275 GHz is repeated for FS input power 0, 10 and 20 dBm with 50 dBi peak FS antenna gain.

A5.2.3 Summary

Atmospheric attenuation independent of free-space losses at 275-450 GHz is not sufficient to provide compatibility between FS and RAS operations in the absence of other considerations.

For the case of operations at the same geographic elevation, care must be taken so that FS beams do not point too nearly toward an RAS site. The size of the avoidance angle will depend on the details of the actual FS beam pattern that is used in any situation, among other variables. For the case of high-elevation RAS operations in direct line of sight of FS operations at much lower elevations, FS beams may be directed in azimuth toward the RAS site for all frequencies as long as FS elevation angle is 10 degrees or less, up to 11 km or at sufficiently horizontal separations.

Scenarios involving aggregate interference from multiple-entry FS deployments will require detailed modelling based on the details of each situation.

A5.3 Study 2: Compatibility analysis between FS and RAS in the 275-325 GHz band

As Report ITU-R RA.2189 indicated, the worst-case interference scenario is that transmitting antennas of LMS or FS stations are directly pointing at a radio telescope, with both transmitter and telescope at a high elevation. However, LMS stations output power and antenna gain are expected to be much lower than that of FS applications. Given this the following sharing study focuses on interference between outdoor FS stations and the radio astronomy service.

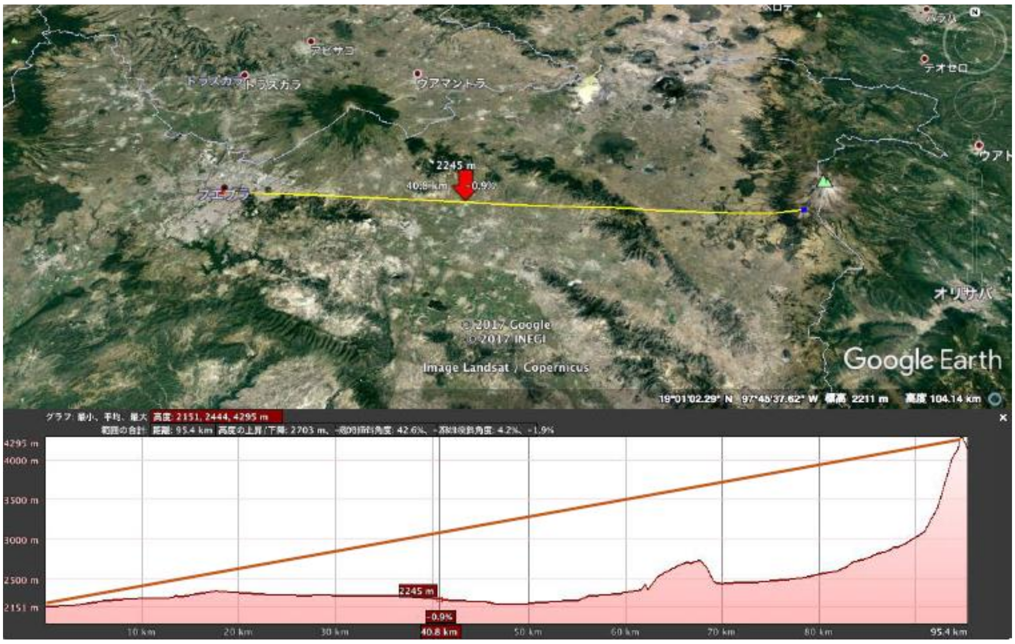
A5.3.1 RAS sites

Table 11 summarizes radio astronomy sites whose locations are generally on high mountaintop and isolated areas. The distance, for example, between Granada (population 0.24 M) and Pico de Veleta, Grenoble (0.15 M) and Plateau de Bure, Puebla (2.5 M) and Sierra Negra are 20 km, 60 km and

90 km, respectively. 300-GHz fronthaul/backhaul may not be deployed in Granada and Grenoble due to low population. The 300-GHz fronthaul/backhaul may be deployed in dense urban area of Puebla because of high population, but the other two cities may not deploy the 300-GHz system due to the lack of traffic. Figure A5-5 shows the terrain profile between Puebla and Large Millimeter Telescope in Sierra Negra. There is possibility of line-of-sight propagation path whose distance is about 40 km.

FIGURE A5-5

Terrain profile between Puebla and LMT in Sierra Negra



A5.3.2 Protection of RAS stations from FS stations operating in the 275-350 GHz band

Figure A5-6 shows the minimum separation distances between the FS station whose output power is 20 dBm, antenna gain 50dB, as shown in Table 7 and a radio telescope. A similar "close-to-worst-case" terrestrial scenario for interference to the radio astronomy service in Report ITU-R RA.2189-1 is also used for calculation without both rainfall and foggy atmospheric attenuation, but the altitude of both FS and RAS antennas is changed from 0 m to 4000 m for evaluation of the separation distance. The minimum separation distance is calculated from equation (1).

$$P_R = P_T + G_T + G_R - P_L - Pclutter - A \geq SH \quad (1)$$

where:

- P_R: received power of radio telescope site
- P_T: FS transmitter power shown in Table 2
- G_T: FS antenna gain shown in Table 2
- G_R: antenna gain of the radio telescope in the direction of the transmitter, which is assumed to be 0 dBi in accordance with Recommendation ITU-R RA.769
- P_L: free-space loss in accordance with Recommendation ITU-R P.525
- $Pclutter$: Clutter loss as shown in Fig. A2-3
- A: atmospheric attenuation in accordance with Recommendation ITU-R P.676
- SH: Threshold level of interference harmful to radio astronomy observations in Table 9.

The calculation results clearly indicate that the separation distance below 45 km which is shorter than that between Puebla and Sierra Negra, and even that between Grenoble and Plateau de Bure can be achieved, if the estimated clutter loss shown in Annex 2 is added in the calculation. However, the entire distribution of the clutter loss is preferable for estimation of the separation distance. Since the levels of interference harmful to radio astronomy observations at 265 GHz and 305 GHz are only specified in Table 9, the levels between 265 GHz and 345 GHz are interpolated using linear approximation, as shown in Table A5-1. It should be noted that the terrain shielding and the deviation of FS antenna direction from the pointing direction to RAS station, as well as the change of an altitude from 3 000 m to 0 m of FS station may further reduce the separation distance. Figure A5-7 shows the separation distance without clutter loss.

FIGURE A5-6

Minimum separation distance including estimated clutter loss between FS station and radio telescope which does not exceed radio astronomy interference thresholds given in Table A5-1

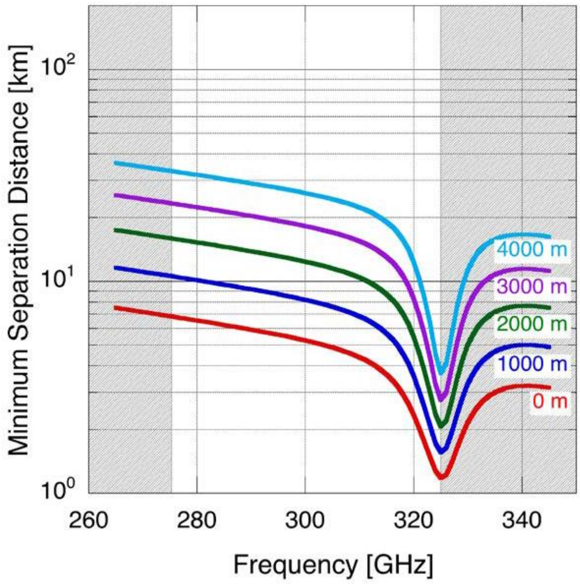


FIGURE A5-7

Minimum separation distance without clutter loss between FS station and radio telescope which does not exceed radio astronomy interference thresholds given in Table A5-1

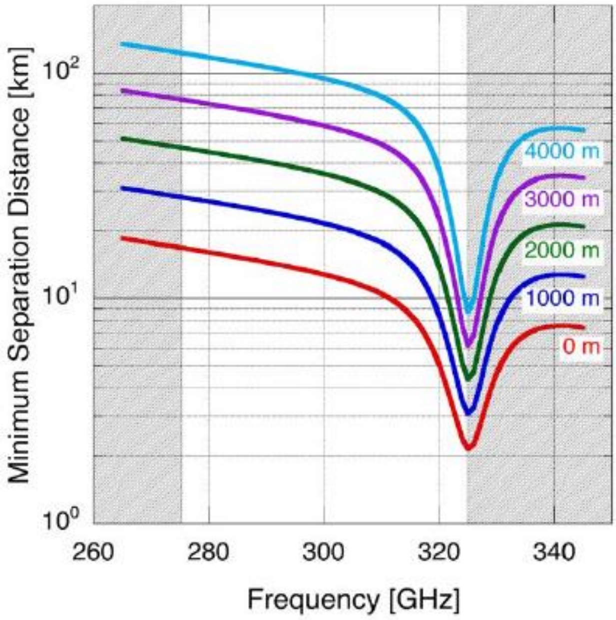


TABLE A5-1

Interpolation of threshold levels of interference calculated from Table 9

Frequency (GHz)	S_H (dB(W/(m^2 · Hz)))	Frequency (GHz)	S_H (dB(W/(m^2 · Hz)))	Frequency (GHz)	S_H (dB(W/(m^2 · Hz)))
265	−195.4 [(1)]	295	−194.05	325	−192.7
270	−195.175	300	−193.825	330	−192.475
275	−194.95	305	−193.6	335	−192.25
280	−194.725	310	−193.375	340	−192.025
285	−194.5	315	−193.15	345	−191.8[1]
290	−194.275	320	−192.925		

(1) The threshold levels at 265 GHz and 345 GHz were provided from Table 9, and the others are calculated by linear interpolation approximation.

A5.3.3 Summary of Study 2

Atmospheric attenuation is not sufficient to provide compatibility between FS and RAS stations in the absence of other techniques. However, the terrain shielding, the deviation of FS antenna direction from the pointing direction to RAS station, and the change of an altitude from 3 000 m to 0 m of FS station further reduce the separation distance. These specific conditions are necessary for protection of RAS station, on a case by case basis.

A5.4 Study 3: Protection of RAS stations from FS stations operating in the 275-450 GHz band

Calculations were based on equation (1) contained in Study 2.

The detailed calculations for all considered scenarios are given in Table A5-2.

FIGURE A5-8

Minimum separation distance including estimated clutter loss between FS station and radio telescope which does not exceed radio astronomy interference thresholds given in Table 9 (continuum observation)

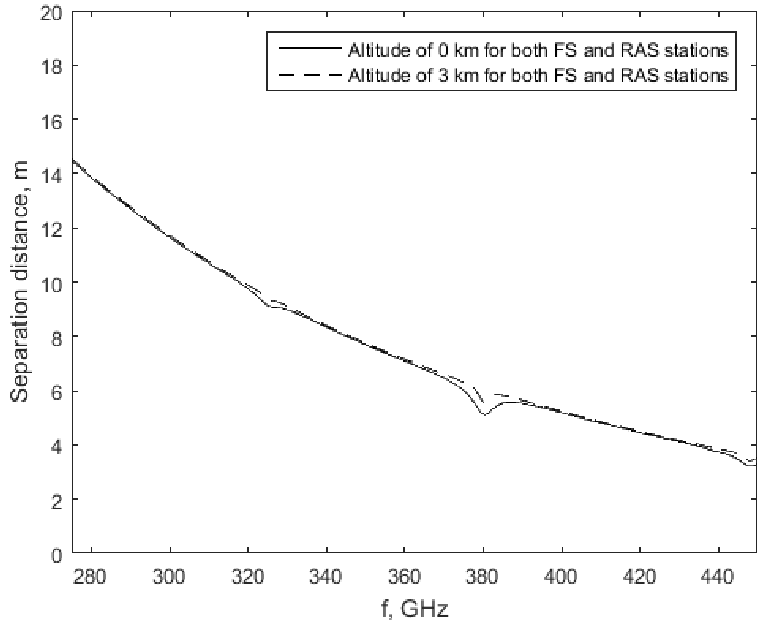


FIGURE A5-9

Minimum separation distance including estimated clutter loss between FS station and radio telescope which does not exceed radio astronomy interference thresholds given in Table 10 (spectral-line observation)

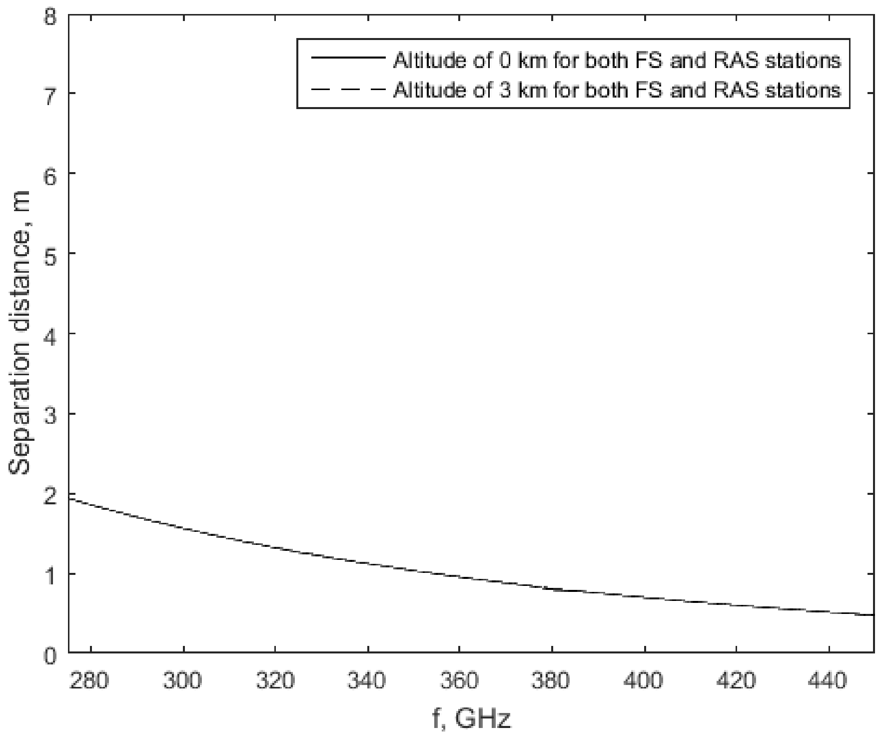


FIGURE A5-10

Minimum separation distance without clutter loss between FS station and radio telescope which does not exceed radio astronomy interference thresholds given in Table 9 (continuum observation)

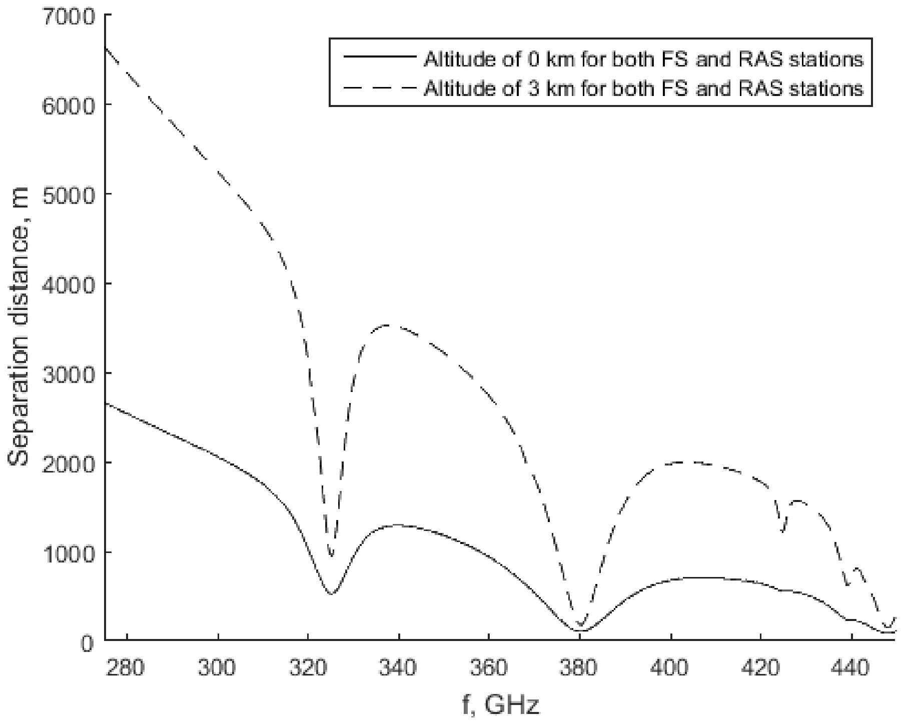


FIGURE A5-11

Minimum separation distance without estimated clutter loss between FS station and radio telescope which does not exceed radio astronomy interference thresholds given in Table 10 (spectral-line observation)

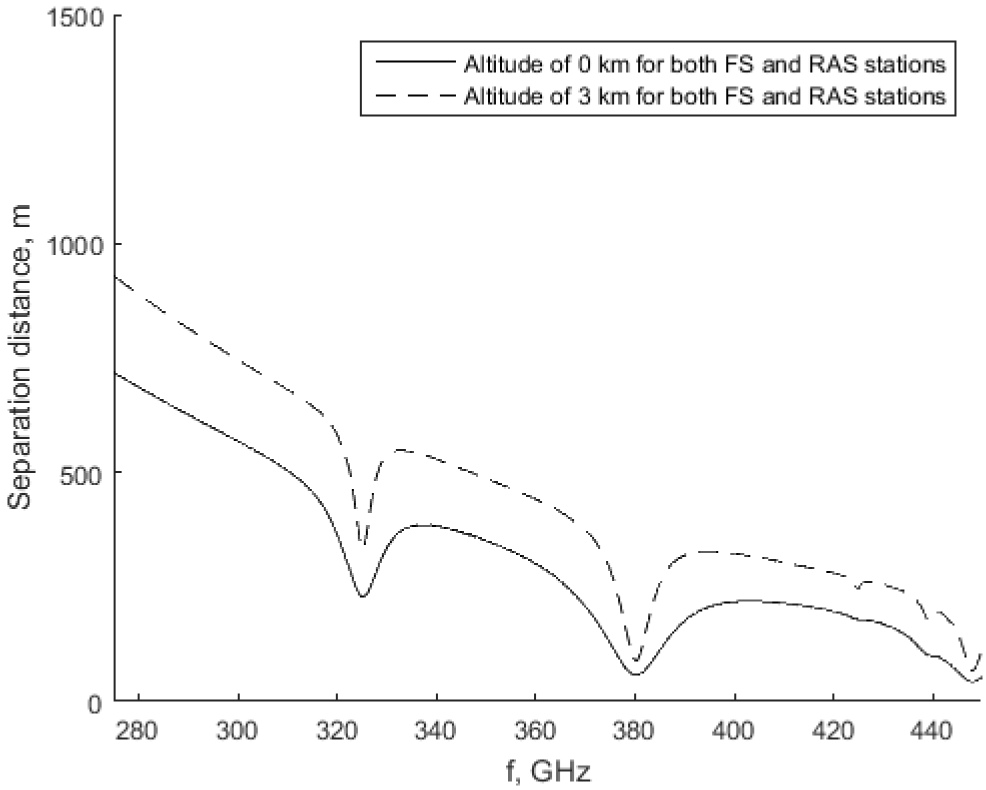


TABLE A5-2

Separation distance calculation results

Frequency (GHz)	Maximum interference level (dBW/Hz)	PT + GT + GR (dBW/Hz)	Separation distance (m)	Clutter loss (dB)	Free space loss (dB)	Atmospheric attenuation (dB/km)
Continuum observation						
275 (altitude 0m)	–214.45	–53	**14**	47	102.69	3.6817
400 (altitude 0m)	–208.8295	–53	**5.1**	47	97.31	9.3321
275 (altitude 3km)	–214.45	–53	**14**	47	102.69	0.4274
400 (altitude 3km)	–208.8295	–53	**5.1**	47	97.31	2.2811
275 (altitude 0m)	–214.45	–53	**2660**	0	149.68	3.6817
400 (altitude 0m)	–208.8295	–53	**680**	0	141.09	9.3321
275 (altitude 3km)	–214.45	–53	**6635**	0	157.62	0.4274
400 (altitude 3km)	–208.8295	–53	**1980**	0	150.37	2.2811
Spectral-line observation						
275 (altitude 0m)	–194.95	–53	**2**	47	83.98	3.6817
400 (altitude 0m)	–189.3295	–53	**0.8**	47	78.42	9.3321
275 (altitude 3km)	–194.95	–53	**2**	47	83.98	0.4274
400 (altitude 3m)	–189.3295	–53	**0.8**	47	78.42	2.2811
275 (altitude 0m)	–194.95	–53	**720**	0	138.33	3.6817
400 (altitude 0m)	–189.3295	–53	**218**	0	131.21	9.3321
275 (altitude 3km)	–194.95	–53	**930**	0	140.56	0.4274
400 (altitude 3km)	–189.3295	–53	**320**	0	134.54	2.2811

It should also be taken into account that the probability that the maximum of FS antenna radiation pattern coincides with direction towards RAS station isn't high (for 50 dB antenna gain the antenna beamwidth is 0.53 degrees according to Recommendation ITU-R F.699 and for 24 dB antenna gain the beamwidth is 10.6 degrees).

Based on the presented results the preliminary conclusion may be drawn that the sharing between FS and EESS (passive) may be possible in the frequency range 275-450 GHz taking into account propagation conditions and with use of terrain shielding or deviation of FS antenna direction from the pointing direction to RAS station.

It should also be taken into account that the probability that the maximum of FS antenna radiation pattern coincides with direction towards RAS station isn't high (for 50 dB antenna gain the antenna beamwidth is 0.53 degrees according to current version of Recommendation ITU-R F.699 and for 24 dB antenna gain the beamwidth is 10.6 degrees). On Figs A5-12 and A5-13 the same curves as on Figs A5-8 and A5-9 are given but for three FS antenna discrimination angles relative to the direction on RAS station (10, 20 and 30 degrees).

FIGURE A5-12

Minimum separation distance including estimated clutter loss between FS station and radio telescope which does not exceed radio astronomy interference thresholds given in Table 9 (continuum observation) taking into account antenna discrimination

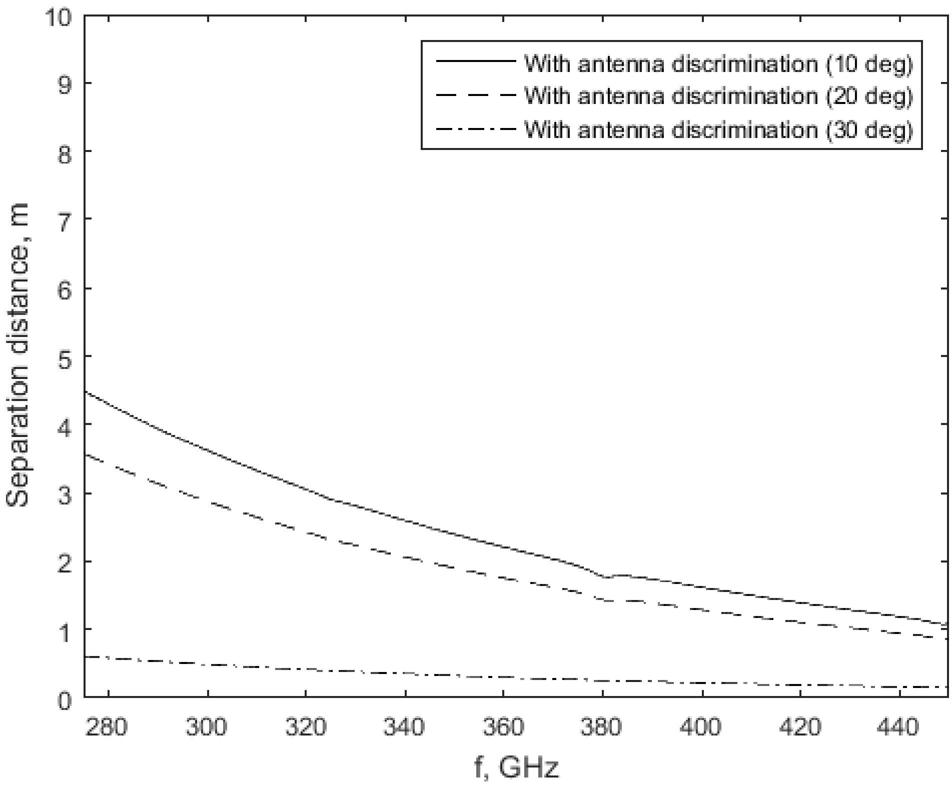
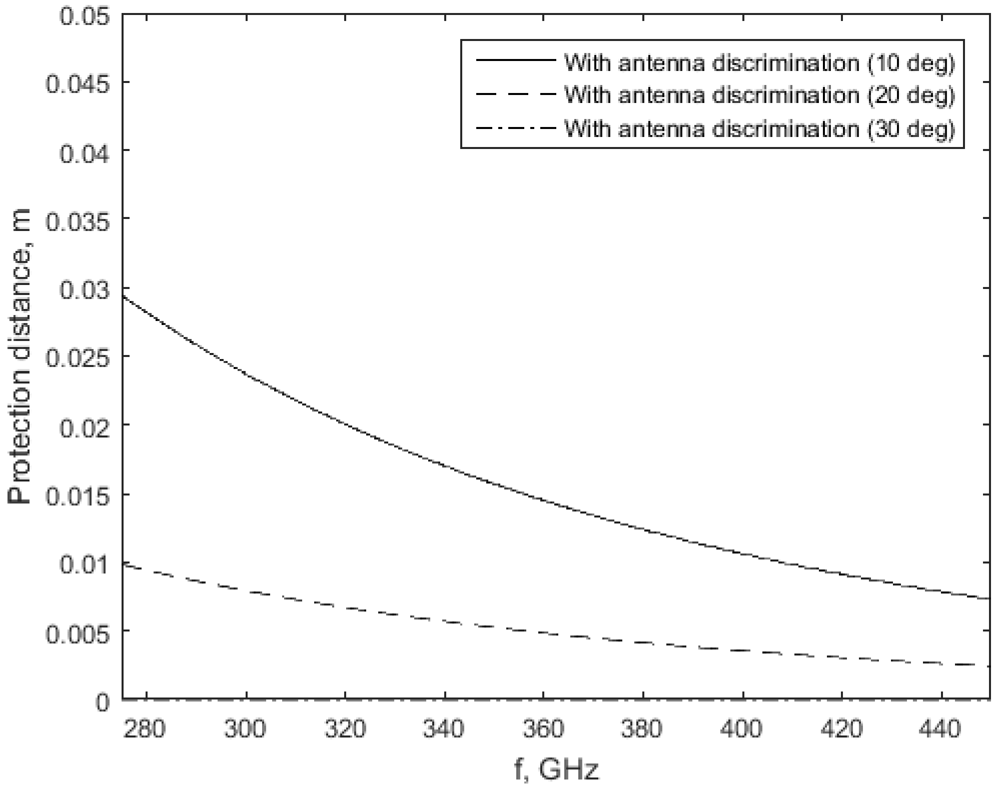


FIGURE A5-13

Minimum separation distance including estimated clutter loss between FS station and radio telescope which does not exceed radio astronomy interference thresholds given in Table 10 (spectral-line observation) taking into account antenna discrimination



Based on the presented results the preliminary conclusion may be drawn that the sharing between FS and EESS (passive) may be possible in the frequency band 275-325 GHz as well as in the frequency band 380-450 GHz, but in the frequency band 380-450 GHz it is simpler to obtain the sharing taking into account propagation conditions.

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